SIZE-FRACTIONATED CHLOROPHYLL AND PRIMARY PRODUCTIVITY AND NUTRIENT DISTRIBUTIONS OFF THE WEST COAST OF VANCOUVER ISLAND

by

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ABSTRACT

Spatial and temporal variability of nutrients, chlorophyll and primary productivity off the west coast of Vancouver Island are not well studied. This study examined how dissolved nutrients and size-fractionated biomass and primary productivity vary in time and space and evaluated the relative contribution of >5 μm size fraction of phytoplankton to total biomass and primary productivity.

Size-fractionated primary productivity, and physical, chemical, and biological characteristics were studied during spring, summer and fall cruises for 1997 and 1998. Studies were conducted at four transects extending across the continental shelf, perpendicular to the west coast of Vancouver Island. Transects were over the La Pérouse Bank, over Barkley Canyon, off Estevan Point and off Brooks Peninsula.

Physical, chemical and biological characteristics of shelf regions were distinct from beyond shelf regions and showed a strong cross-shelf gradient. The shelf region was characterized by lower temperature and lower salinity. In addition, higher nitrate and silicic acid, and higher chlorophyll and primary productivity were observed in the shelf region compared to the beyond shelf region. Variability was very high off the west coast of Vancouver Island; often the mean and the standard deviation were similar.

This study was conducted during a strong El Niño (1997/98) and La Niña (1998) event and interannual variation was evident. The mixed layer depth was shallower, nitrate, silicic acid and primary productivity were higher during El Niño. In contrast, phytoplankton biomass, diatom abundance and the relative contribution of >5 μm sized phytoplankton were higher during La Niña.

The >5 μm sized phytoplankton were dominated by the diatoms *Chaetoceros* spp. and *Leptocylindrus danicus* and contributed substantially to the biomass (62%) and primary productivity (57%) off the west coast of Vancouver Island. The relative contribution was higher in shelf regions than in beyond shelf regions. This study clearly showed that the contribution of the >5 μm size fraction was greatest at high biomass concentrations and high productivity rates supporting the idea that in order to reach high biomass and productivity, large cells are required.

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GENERAL INTRODUCTION

Traditionally the growth rate of phytoplankton in the ocean has been regarded to be limited by nitrogen, but this view has recently been challenged by evidence that indicates during particular periods and in certain regions other nutrients or trace metals may also limit growth. For example, the equatorial Pacific may be phosphorus limited (Smith, 1984; Harrison *et al.*, 1990; Karl *et al.*, 1997). New evidence suggests that silicate may regulate primary production in upwelling regions of the equatorial Pacific (Dugdale and Wilkerson, 1998), the Southern Ocean (Nelson and Truguer, 1992) and in the Gulf Stream (Nelson and Brzezninski, 1990). The growth of phytoplankton in certain areas called high nitrate, low chlorophyll (HNCL) regions are now known to be limited by the availability of iron. Oceanic regions such as the equatorial Pacific (Cole *et al.*, 1996), the Southern Ocean (Boyd *et al.*, 2001), the NE subarctic Pacific (Martin and Fitzwater, 1988; Boyd *et al.*, 1996) and California coastal upwelling regions such as Big Sur (Hutchins and Bruland, 1998) are now known to be iron limited. Carbon limitation of photosynthesis has been considered rare because of the high availability of inorganic carbon in the oceans, but some researchers suggest that carbon may control phytoplankton growth and phytoplankton community structure (Tortell, 2000).

Vertical mixing of phytoplankton in the water column is very important as mixing controls the light and nutrient regimes to which the phytoplankton are exposed. Lack of mixing may cause photoinhibition of phytoplankton if the cells are exposed to very high irradiances (Neale, 1987). Conversely, phytoplankton may suffer an 'energy crisis' when mixed from high to low light (Falkowski and LaRoche, 1991). During this crisis the cell shifts its focus from the synthesis of molecules necessary for growth to the production of light harvesting complexes that allow for adaptation and growth to low light environments. This shift is called photoacclimation and it causes a temporary decrease in phytoplankton growth rate. It is important that the depth of the mixed layer is no deeper than the critical depth. The critical depth is defined as the depth above which photosynthetic production for the water column equals the respiration of the water column per unit surface area. If mixing is deeper than the critical depth, phytoplankton respiration will exceed photosynthesis and there will be no growth. Deep mixed layers can cause a depression in photosynthesis (Huntsman and Barber, 1977) and nitrate uptake rates (Zimmerman *et al.*, 1987) because the phytoplankton are maintained in light-limited conditions.

Coastal Upwelling

The aquatic environment accounts for approximately 40% of the total photosynthesis on earth (Falkowski, 1994) and much of this photosynthesis occurs in coastal upwelling regions which occupy only 0.1% of the total ocean area. 95% percent of the world's fisheries occurs within 320 km of the shore (Thurman and Trujillo, 1999). They are fertile regions relative to oceanic regions and they are characterized by relatively high levels of biomass and phytoplankton (Barber and Smith, 1981). Primary productivity rates >300 g C m^{-2} y^{-1} are common in upwelling regions compared to <50 g C m^{-2} y^{-1} in oceanic regions (Ryther, 1969). Coastal upwelling occurs along the western margins of continents in both the southern and northern hemispheres. When northwest winds transport water offshore in the Northern Hemisphere, cold nutrient-rich subsurface water is upwelled to the surface to replace the water advected offshore. In the absence of upwelling, nutrient-rich subsurface water is vertically separated from the nutrient-poor surface waters by a density gradient that prevents mixing. Upwelling is a physical process that provides an injection of new nutrients and a "seed" phytoplankton population to the euphotic zone and in the presence of light, rapid growth can occur. Following an upwelling event, phytoplankton respond to high nutrients and light availability by a series of specific physiological transition stages that occur along the axis of the upwelling plume. Jones *et al.*, (1983) characterized a series of 4 idealized zones that are summarized by Wilkerson and Dugdale (1987) as a 'conveyor belt' of nutrient and carbon phytoplankton processes in an upwelling zone. These zones are summarized in Figure 1. In Zone 1, upwelling occurs and phytoplankton nutrient and carbon uptake rates are "shifted down" because the cells are taking up nutrients and growing considerably slower than their maximal rates. This lag is due to cells becoming acclimated to both high nutrient concentrations and near-surface light intensities and/or a period of biological conditioning may be required because of inherent toxic factors (Barber and Huntsman, 1977). Zone 2 is downstream of the upwelling plume where cells have acclimated to the new conditions and uptake rates increase or are "shifted up". Initially, nitrogen uptake rates are elevated, but nitrogen uptake is quickly followed by increases in carbon uptake and growth rate. In Zone 3, phytoplankton rate processes are functioning at their maximal rates and nutrients will quickly be depleted and phytoplankton biomass will increase. Finally in Zone 4, nutrient concentrations are exhausted by the fast-growing "shifted-up" phytoplankton cells and consequently cells undergo a "shift down" in rate processes. Following nutrient exhaustion, phytoplankton rapidly sink out of the photic zone (Bienfang and Ziemann, 1992). The time and space domain where these sequences of physiological changes take place is only 8-10 days within 30-60 km of the coast (MacIsaac *et al.*, 1985; Zimmerman *et al.*, 1987).

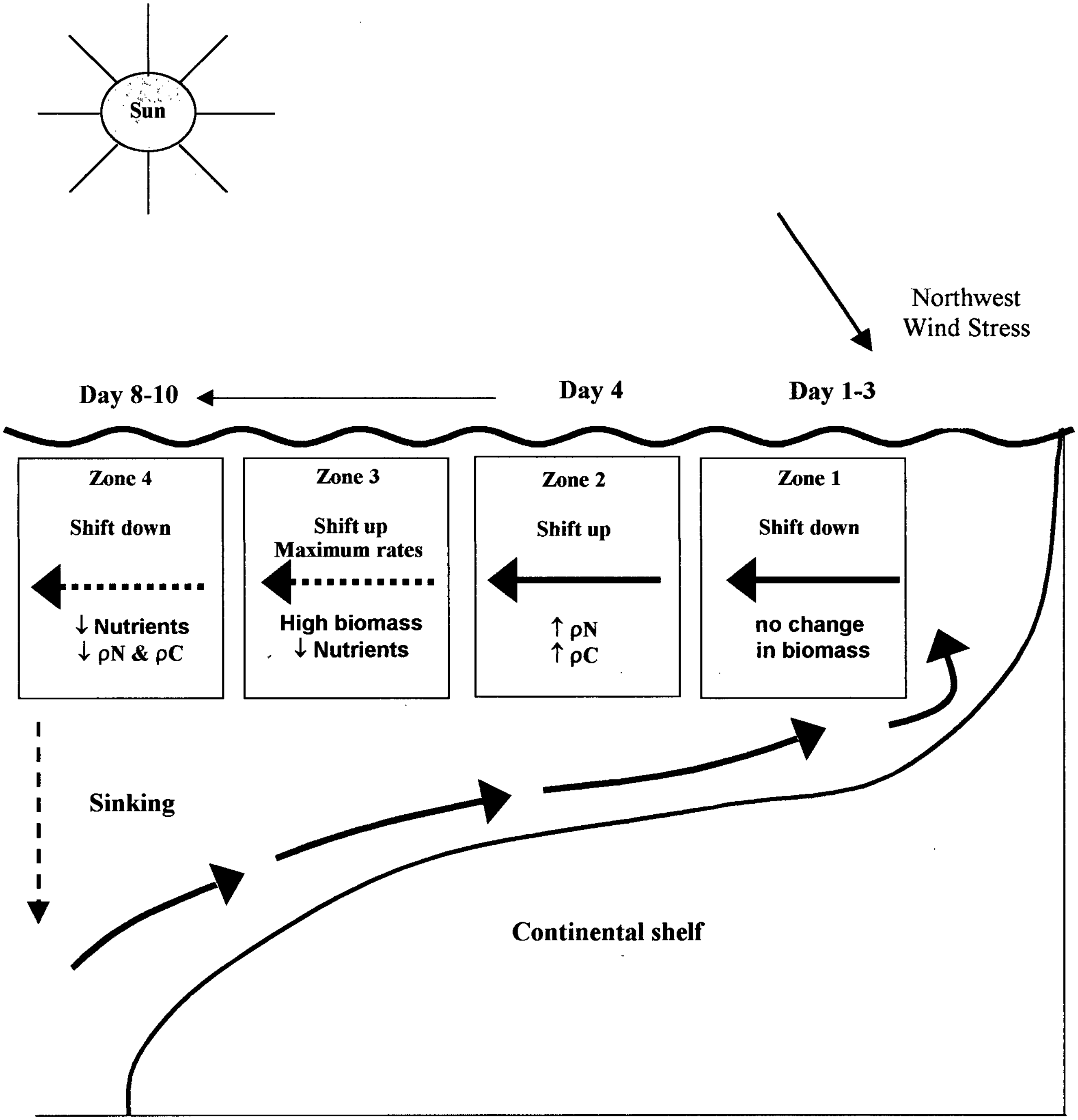

Figure 1 Idealized cycle of nutrient and carbon phytoplankton processes in an upwelling region (adapted from Wilkerson and Dugdale, 1987). Solid arrows represent a nutrient rich upwelling water mass and all dashed arrows represent the nutrient deplete upwelled plume. ρN represents nitrate uptake rate and ρC represents carbon uptake rates. Day # on top of each zone estimates the days since upwelling was initiated. The sun represents solar heating necessary for stabilization of water column.

Globally, picoplankton (0.2-2.0 μm) account for more than 80% of primary productivity in oligotrophic waters (Stockner and Antia, 1986), but in upwelling regions Malone (1980) has shown that phytoplankton biomass is characterized by episodic production of chain-forming diatoms or large-celled diatoms or dinoflagellates. There is increasing evidence from ^{15}N tracer experiments that show that the larger size fractions primarily use new nitrogen sources (NO_3^-) and nanoplankton and picoplankton primarily use regenerated sources such as ammonium and urea (Probyn, 1985; Probyn *et al.*, 1990). Often diatoms develop in part due to the rapid uptake of nutrients and large vacuoles that allow for storage of nutrients (Turpin and Harrison, 1979)

The importance of cell size

The size of organisms at any trophic level can be a determining factor in the length of the food chain, the ecological efficiency of energy transfer, and the yield of organisms living at the highest trophic level (Ryther, 1969). Ryther (1969) showed that the yield of fish from a marine ecosystem dominated by large-celled phytoplankton was greater than from areas dominated by small-celled phytoplankton. Cushing (1989) suggested that food chains based on large phytoplankton are ecologically more efficient than those based on small phytoplankton because small phytoplankton can not be directly grazed by copepods. As a result, a greater proportion of the carbon fixed in small cells is lost through respiration and excretion because of the additional trophic level introduced by microzooplankton grazing on small phytoplankton, before being consumed by mesozooplankton.

The size structure of phytoplankton assemblage affects the vertical flux of organic carbon in the oceans; only the production of large, rapidly sinking particles can result in a significant transfer of anthropogenic carbon dioxide into the deep ocean (Joint *et al.*, 1993). This flux of organic carbon is often called export production (Berger *et al.*, 1989) and in nutrient replete regions it can account for up to 50% of the total carbon fixation (Bienfang and Ziemann, 1992). Export production derived from the uptake of inorganic carbon by phytoplankton results in the transfer of carbon out of the upper ocean to the deep ocean. Phytoplankton are an important component of this biological pump.

Parsons and Takahashi (1973) suggested that phytoplankton cell size selectivity is determined on the basis of ecological and species specific physiological data such as: 1) the rate of nitrate or ammonium uptake by the cell, 2) the extinction coefficient of the water, 3) the mixed layer depth, 4) the light intensity, 5) the sinking rate of phytoplankton, and 6) the upwelling velocity of water. They suggested the physiological differences between *Ditylum brightwelli* (30 μm) and *Emiliania huxleyi* (5 μm) can account for different growth rates in different environments. Only in regions of high light intensity and high nutrient concentrations, is it possible for large cells to grow faster than small cells. The uptake of nitrogen follows Michaelis–Menten uptake kinetics where V_{max} is the maximum uptake rate and K_s is the concentration supporting half the maximum rate of uptake (half-saturation constant) (Dugdale, 1967). Eppley *et al.* (1969) have shown that the large variation in V_{max} and K_s of phytoplankton may account for competitive selection. Small cells with high surface area to volume ratios have a competitive advantage over large cells with respect to the acquisition of nutrients. Generally, small cells have a lower K_s and consequently in a low nutrient environment, they should dominate (Dugdale, 1967). There is a general negative relationship between the size of phytoplankton cells and their ability to take up nutrients (Eppley *et al.*, 1969). Conversely, large cells usually have a large storage capacity for nutrients and consequently in environments where nutrients are delivered in pulses, large cells often rapidly acquire and store nutrients and sustain growth for longer periods than smaller cells (Turpin and Harrison, 1979). Often the composition and size structure of the autotrophic assemblage is a major determinant of the quantity of production that can occur. Upwelling regions generally support relatively large phytoplankton stocks typically dominated by large phytoplankton composed mainly of diatoms.

ENSO –El Niño Southern Oscillation

Marine ecosystems undergo large interannual to decadal fluctuations that are beyond those attributable to direct harvest effects. There is increasing evidence that persistent and synchronous ecological changes have occurred that are linked to the variation in interdecadal climate (e.g. Venrick *et al.,* 1987; Beamish, 1993; Beamish *et al.*, 1999). The El Niño Southern Oscillation (ENSO) is a natural climatic process that causes significant variability in living resources.

ENSO is an interannual climatic condition that results in sea-surface warming, and a deeper thermocline and nutricline in eastern boundary currents (Philander, 1983). A deep thermocline is usually correlated with a deeper mixed layer and hence a reduction in productivity due to a decrease in the average light. Because light decreases exponentially as a function of depth, the depth of the surface mixed layer in which phytoplankton are homogeneously distributed, determines the quantity and quality of light that can be harvested by the phytoplankton (Sverdrup, 1953). Often coastal winds do not weaken and in fact, they may intensify during an El Niño because of increased thermal differences between land and sea (Enfield, 1981). Coastal upwelling may still occur, but the thermocline and nutricline are depressed below the depth of entrainment (40-80 m). This effect was seen during the 1982-83

El Niño off the west coast of South Africa where coastal winds and locally forced winds continued through March 1983, but after November 1982, the surface water had significantly reduced nutrients and increased temperatures (Barber and Chavez, 1986)

The effects of ENSO events such as those of 1982/1983 and 1991/1992 which enhanced the poleward movement of warmer water in winter and reduced summer upwelling along much of the west coast of North America, appears to have been responsible for altering the distribution of Pacific hake and salmon and for changing the predator-prey balance for many coastal species (Ware and Thomson, 1983).

ENSO events may have a global geochemical impact also, since algal photosynthesis removes upwelled CO_2 and reduces the pCO_2 gradient between the sea surface and the atmosphere. Gammon *et al.* (1985) found that the rate of increase of CO_2 (pCO2 anomaly) in the atmosphere fell to zero for a period during the 1982-1983 El Niño.

The ENSO event of 1997/8 showed unual development, both in terms of scale and mode of development. Post 1976 ENSO events start to develop in approximately November to December with the largest sea surface temperature anomalies recorded January to March of the preceding year. The 1997/8 El Niño was different in that the first anomalies were seen along the equator in March and by June the anomalies had penetrated through the entire northeastern Pacific. This thesis will examine physical, chemical, and biological parameters during the 1997/8 ENSO event.

The west coast of Vancouver Island

Physical Oceanography

Vancouver Island lies on the west coast of British Columbia (Canada) between approximately 48 to 51°N and 123 to 128.5°W. The western coastline of Vancouver Island has numerous sounds and inlets that vary considerably in their dimensions (Pickard, 1963). Total precipitation varies along Vancouver Island, but generally a maximum occurs in December and a minimum in July (Dodimead, 1967). The river outflow volumes follow the annual cycle of precipitation except for the Gold and Stamp Rivers, which receive snow melt resulting in a second maximum outflow in May.

Shelf width and bathymetric profiles vary considerably along the western margin of Vancouver Island. The continental margin gradually narrows northward of La Pérouse Bank from 65 km wide to just 5 km in width off Brooks Peninsula. Near the southwest tip of Vancouver Island, westward of Juan de Fuca Strait, the continental margin is cut by a deep (>250 m) narrow (≈7 km wide) submarine canyon called the Juan de Fuca Canyon that extends seaward from the mouth of Juan de Fuca Strait. Northwest of this canyon is a series of isolated banks (z = 40-80 m), two additional submarine canyons, Nitinat and Barkley, and semi-enclosed basins (z >120 m). Bottom slopes along banks and basins are steep. The shelf break is approximately delineated at the 200 m isobath (Dodimead, 1985).

The Juan de Fuca Strait shows typical estuarine circulation that has a direct forcing effect on the southern margin of Vancouver Island. Brackish water flows out of the strait at the surface and denser water flows into the Strait near the bottom. The strength of the flow is mainly controlled by runoff from the Fraser River. The flow out of the strait is maximum in early summer when discharge from the Fraser River is maximal.

The Aleutian Low and the North Pacific High are two large scale pressure systems that govern the oceanic wind regimes off the coast of Vancouver Island (Favorite *et al.*, 1976; Thomson, 1981). The location and intensities of these two pressure systems control the prevailing wind patterns along the west coast. Generally, from August to December (Northern Hemisphere fall/early winter) the Aleutian Low intensifies and shifts southward from the Bering Sea to the Gulf of Alaska. Southeasterly to southwesterly winds persist from late August to early spring as air flows counterclockwise around the dominant Aleutian Low. The Aleutian Low then progressively weakens until it is no longer evident in July as the North Pacific High intensifies until it covers the entire Gulf of Alaska during May to August. The resulting pressure pattern of the intensified North Pacific High and the diminished Aleutian Low during May through September, results in northwesterly winds as the air flows clockwise around the dominant North Pacific High pressure cell.

The study area for this thesis falls into the coastal upwelling domain described by Dodimead *et al.* (1963) and is subject to dynamic forcing from wind-induced upwelling. Continental shelf and slope waters off the west coast of Vancouver Island are at the northern end of an extensive Eastern Boundary Current system called the California Current that stretches from Baja California (25°N) to the northern tip of Vancouver Island (50.5° N) (Ware and McFarlane, 1989). Upwelling favorable winds are not as strong as those off the coast of California (Nelson, 1977) but are strong enough to induce classical wind-induced upwelling (Thomson, 1981). Conditions are favorable for upwelling in the summer, roughly from late March to the end of September, followed by a relatively abrupt reversal of the prevailing alongshore winds that produce winter downwelling favorable conditions. Summer wind-induced upwelling occurs during periods of persistent northwesterly (equatorward) coastal winds associated with the establishment of high pressure systems along the coast, while winter downwelling occurs during times of southeasterly (pole-directed) coastal winds associated with the passage of winter lows (Thomson *et al.*, 1989).

There is considerable variability in the timing, duration and intensity of the summer upwelling and winter downwelling season. The summer season starts between early April and late June and lasts 146.4 ± 35.2 days, roughly three times longer than the winter downwelling season which starts in late September and runs until late November and lasts 53.7 ± 28.1 days (Thomson and Ware, 1996). A spring and a fall transition season separate the summer and the winter seasons. There is considerable interannual variability in the timing and duration of these two transitions. The spring transition can occur as early as January during 1995, or as late as mid-April during 1987, and usually lasts 79.2 ± 38.6 days. This variability in timing and duration is caused by changes in the prevailing winds, coastal runoff, alongshore pressure gradients, and other forcing mechanisms (Thomson and Ware, 1996). The fall transition can begin as early as August (1987) or as late as November and lasts 64.8 ± 27.4 days (Thomson and Ware, 1996). The fall transition variability is related to the degree of storm activity in the North Pacific and the positions of storm tracks relative to the coast of North America (Thomson and Ware, 1988). Wind-induced upwelling is dynamic but variable along the west coast of Vancouver Island. Thomson and Ware (1996) report dramatic interannual variations in the intensity of upwelling; for example the current velocity index (a measure of upwelling intensity) shows upwelling intensity during 1993 was approximately three times higher than the upwelling intensity during 1992. Examination of a 32 yr record (1965-1997) of the Bakun Upwelling Index, a measure of upwelling intensity, shows on average that coastal upwelling peaked in 1995 and 1996 and then steady declined to the lowest measurement recorded in 1997 (Robinson and Ware, 1999). Clearly, the relative forcing of wind-induced upwelling on environmental conditions off the west coast of Vancouver Island varies considerably.

The west coast of Vancouver Island is also subject to forcing from the Pacific Ocean. The surface circulation of the NE Pacific is dominated by the Subarctic Current that originates from the mixing of the Kuroshio and Oyashio currents (Dodimead *et al.*, 1963; Tabata, 1975). The Subarctic Current flows eastward and divides into two streams about 300 km offshore at the latitude of Vancouver Island to form the northward-flowing Alaska Current and the southward flowing California Current (Dodimead *et al.*, 1963; Tabata, 1975). In the winter, the northward flowing Alaskan Current intensifies and in response to the prevailing southeasterly winds, the surface flow along the shelf break is northward parallel to the shore (Marmer, 1926; Freeland *et al.*, 1984). This appears to be the northward extension of the Davidson Current that originates off California (Thomas and Emery, 1986). In the winter, the bottom current (up to 1 m s^{-1}) flows to the northwest, and is strongest in the late autumn or winter. In the summer, the surface flow along the shelf break is reversed in response to the shift in the California Current towards Vancouver Island and a reversal in the prevailing winds. Persistent northwesterly winds cause southward surface flow along the shelf break (Figure 2) and surface current speeds are often >40 cm s^{-1} to depths of 50 m (Mackas, 1992). Beneath the shelf break current, the California Undercurrent flows northwest at 5-10 cm s^{-1} along the continental slope below 200 m and is characterized by high salinity (34) and low dissolved oxygen (0.5-2.0 ml l^{-1}) (Hickey, 1979; Thomson, 1981). There is some evidence that suggests that the California Undercurrent extends as far north as Estevan Point (Freeland *et al.*, 1984).

The current pattern along the inner part of the shelf is different from that along the shelf break by the persistent northward flowing Vancouver Island Coastal Current (VICC) (See Figure 2). The VICC is a poleward flowing, buoyancy-driven surface current off the west coast of Vancouver Island (LeBlond *et al.* 1986; Thomson *et al.* 1989). It is a permanent feature of the surface circulation that flows year-round from the entrance of Juan de Fuca Strait and can be found beyond Brooks Peninsula. It is generally confined to the innermost part of the shelf within about 25 km of the coast, but occasionally meanders seaward across the shelf (Freeland *et al.* 1984; Thomson *et al.* 1989). This current is driven by the flux of low density water onto the shelf from Juan de Fuca Strait (influenced by Fraser River discharge) and from freshwater runoff from coastal streams along the west coast of Vancouver Island. These two sources of freshwater differ in the timing of peak discharge and spatial distribution of discharge. Direct discharge from coastal streams peaks during the fall winter rainy season, while discharge from the Fraser River peaks in June. This current is characterized by low surface salinity (30-31.5). Maximal near surface speeds can reach 50 cm s^{-1} within the core of the current, but average longshore flow from October - March is ≈ 25 cm s^{-1} and from April – September is ≈ 10 cm s^{-1}. Current speeds are reduced in the summer because strong northwesterly winds tend to retard the flow while during the winter southeasterly winds augment the northward flow.

Summer and autumn circulation at the southern end of Vancouver Island is often dominated by the Tully eddy or alternatively called the Juan de Fuca eddy (Figure 2) This was first observed by Tully (1942) and it is situated over the southwest margin of Vancouver Island. Freeland and Denman (1982) found that this cyclonic eddy is controlled by the interaction between bathymetry and the local flows off the southwest margin of Vancouver Island. A shallow region called Finger Bank, deflects currents to the west and starts the eddy on its course (Freeland and Denman, 1982). The average residence time of water in the upper 40 m is 4.2 d, with a range of 1.2 to 17 d and water exits either north onto La Pérouse Bank or south to Washington. (Freeland, 1988). Although this eddy is a local effect, it does dominate the productivity in this region during the summer months (Mackas and Sefton, 1982).

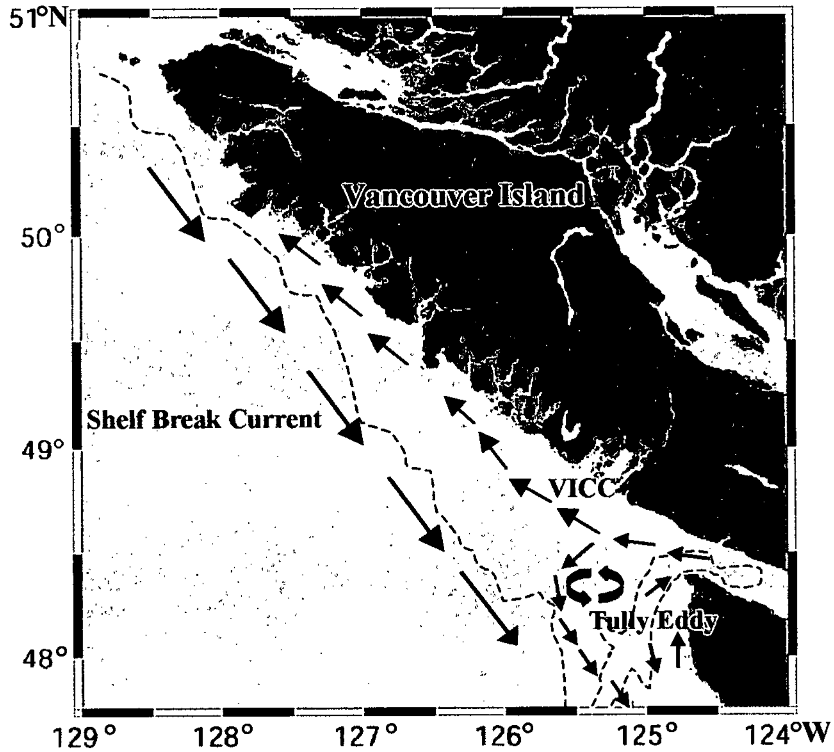

Figure 2 Surface circulation off the west coast of Vancouver Island in summer (redrawn from Thomson *et al.*, 1989). Dashed line marks the 200 m contour. Vancouver Island coastal current =VICC.

Long-term coastal temperature variability (Brainard and McLain, 1985) and long term variability in coastal sea levels (Enfield and Allen, 1980) has been studied for many years. Thomson *et al.* (1984) examined a 40 year sea-surface temperature data set of and found decadal scale cycles in the water temperature along the west coast. Current observations suggest the ocean climate has recently undergone a change during the 1990s. Sea-surface temperatures measured at Amphitrite Point lighthouse on the west coast of Vancouver Island show two large temperature anomalies during the 1990's, the 1992 and the 1997 El Niños (Robinson and Ware, 1999). Relative to sea-surface temperatures dating back to 1000's, the

1990's were an unusually warm decade, which ended abruptly in 1999 with conditions typical of the 1960's and early 1970's (Mann *et al.*, 1999).

Ecological Dynamics

The physical oceanography of the west coast of Vancouver Island has been studied much more extensively than the biological oceanography and generally studies of ecological dynamics have been restricted to the southern margin of Vancouver Island. Historically, several large research programs have been completed in this area including Coastal Oceanic Dynamic Experiment (CODE), La Pérouse, and Marine Survival of Salmon Species (MASS) program. CODE was initiated to study the general circulation, the dominant physical mechanisms, and the resulting planktonic ecosystem dynamics on the continental shelf. The La Pérouse project was initiated in 1985 following the major 1982/83 El Niño event in the Pacific Ocean to investigate the causes of annual and interannual recruitment variability in herring, sablefish, Dungeness crab and Pacific cod. The MASS program was initiated to investigate the interrelationships between biophysical events and salmon distribution and survival on an annual and interannual time scale.

The surface waters off the west coast of Vancouver Island are characterized by high levels of dissolved nutrients (Mackas *et al.*, 1980; Denman *et al.*, 1981, 1982) supplied by wind mixing, episodic wind-driven upwelling, topographically controlled upwelling (Freeland and Denman, 1982) and the outflow from Juan de Fuca Strait where deep nutrient-rich water is advected to the surface by tidal mixing and estuarine circulation (Mackas *et al.*, 1980). The outflow from Juan de Fuca is a potential source of nutrients for phytoplankton for both the shelf and offshelf regions due to cross-shelf transport of water to the outer shelf (Mackas and

Yelland, 1999; Crawford, 1989). Mackas *et al.*, (1980) estimated the flux of nitrogen (nitrate + nitrite) out of Juan de Fuca Strait to be 30 kg s^{-1} depending on the rate of outflow of water from Juan de Fuca and the nitrogen concentration of this outflow water and estimates that wind-induced upwelling accounts for on average ~20% of the estimated contribution from estuarine flow. The relative contribution of upwelling may increase 2–3 fold during periods of active upwelling, but on average the relative contribution of upwelling is less than Juan de Fuca. Crawford and Dewey (1989) estimated nitrogen flux rates for wind-driven upwelling at 15 kg s^{-1}, wind mixing in the upper 20 m at 5 kg s^{-1} and turbulent mixing less than 2 kg s^{-1}. In summary, the nutrient rich surface waters off the west coast of Vancouver Island are mainly derived from estuarine flow out of the Juan de Fuca, followed by upwelling, and tidal mixing (Crawford and Dewey, 1989). Surface nitrate is rarely depleted to undetectable levels. At the southern margin of Vancouver Island, shoreward of the shelf break current and extending into the Juan de Fuca Strait, near surface nitrate in excess of 20 μM is common. On average, the nitrate concentration of the inner part of the shelf is >10 μM, and at beyond shelf regions, nitrate concentrations are lower but generally between 1-5 μM.

The shelf region off Vancouver Island is characterized by relatively high phytoplankton biomass. Maximum chlorophyll concentrations between 10-50 mg chl m^{-3} are frequently found (Mackas and Sefton, 1982), and generally there is a cross-shelf gradient. On average, nearshore surface layer chl *a* concentrations >5 mg chl m^{-3} are common compared to 1-3 mg m^{-3} for offshore regions (Mackas, 1992). Phytoplankton biomass is patchy in distribution. Denman *et al.* (1981) found persistent regions of high surface chlorophyll (20 mg chl m^{-3}) along a nearshore 20 km wide band and a zone of high biomass centered over the 80 m bathymetric contour. The seasonal cycles of the shelf and the beyond shelf are different. Phytoplankton biomass on the inner shelf is persistently high in the spring, summer and fall; on average biomass peaks in August/September. In the offshore regions, biomass blooms in March/April, decreases in May and June coupled with depletion of nutrients and increases throughout the season as nutrients increase until October/November when phytoplankton are likely limited by light.

The studies by Denman *et al.* (1981), Mackas and Sefton (1982), Forbes and Denman (1991), and Taylor and Haigh (1996) are among the few to analyze phytoplankton species composition off the west coast of Vancouver Island. Most studies were limited to the southwest margin of Vancouver Island and limited to identification of the dominant species, except for the investigation of Taylor and Haigh (1996) who completed a systematic study of the microplankton community in Barkley Sound. Taylor and Haigh (1996) found and identified potentially harmful phytoplankon species in B.C. coastal waters. Forbes and Denman (1991) focussed exclusively on the distribution of *Pseudo-nitzschia pungens* (formally *Nitzschia pungens)*, a diatom known to produce domoic acid and shellfish poisoning (Subba Rao *et al.*, 1988). Denman *et al.* (1981) found the diatoms, *Rhizosolenia setegera* (~300 µm long) and *Nitzchia* spp. (~40 µm long) dominated the phytoplankton assemblage when biomass was high. There have been no detailed taxonomic studies off the west coast of Vancouver Island that extend to the northern reaches of Vancouver Island, although Taylor and Waters (1982) have studied the subarctic Pacific beyond the continental shelf. Large diatom populations typically develop during late July and August (Mackas *et al.*, 1980; Denman *et al.*, 1981; Mackas and Sefton, 1982).

Detailed studies examining temporal and spatial variability of primary productivity are limited on the west coast of Vancouver Island. Most of the study spatially focussed on the southern margin of Vancouver Island during short-time scales. Persistent zones of high primary productivity that last for several months have been measured on the southwestern coast of Vancouver Island (Denman *et al.*, 1981). Primary productivity at the surface as high as 136 mg C m^{-3} h^{-1} was measured during May of 1981. During July and August, maximum primary productivity was 49.1 and 61.4 mg C m^{-3} h^{-1} respectively. The assimilation numbers measured were 3.92 and 3.75 mg C mg chl^{-1} h^{-1}, while Forbes and Denman (1991) found assimilation numbers ranging from 3.5-17.5 mg C mg chl^{-1} h^{-1}.

The La Pérouse Bank is one of the most productive fishing areas in the Northern Hemisphere and it generates a landed value to the British Columbia economy in excess of $40 million annually (Ware and Thomson, 1991). The west coast of Vancouver Island is an important feeding and breeding region for many pelagic fish species including Walleye pollock, Pacific cod, Pacific halibut, Pacific hake, Pacific sardine, Pacific herring, Pacific mackerel and northern anchovy. It is a migration corridor for returning salmon. When phytoplankton stocks are abundant, Pacific hake, sardine and mackerel migrate into Canadian waters in the summer to feed and return to southern Baja California where they spawn in the winter and spring (Ware and McFarlane, 1988). Recent changes in the pelagic fish community of species abundance and production dynamics have been observed during the 1990's off the west coast of Vancouver Island. Increased biomass of mackerel, a reappearance of Pacific sardine (Hargreaves *et al.* 1994), more abundant but smaller Pacific hake (Ware and McFarlane, 1995) and poorer growth of Pacific herring have been observed (Tanasichuk, 1997).

Global Ocean Ecosystem Dynamics Program (GLOBEC)

In 1997 the Canadian GLOBEC (Global Ocean Ecosystem Dynamics) program set out to understand how living marine resources are affected by variability in their physical environment. Previous work by the La Pérouse Project, MASS (Marine Survival of Salmon), COPRA and salmon-index streams programs, focussed exclusively on the southern margin of the west coast of Vancouver Island and found strong upstream influences on water properties (Thomson *et al.*, 1989). One objective of GLOBEC was to extend the study area to the northern region of Vancouver Island to provide good spatial and temporal coverage for the west coast of Vancouver Island.

Despite extensive studies on the southern margin of Vancouver Island, little information is available for primary productivity. Previous studies have focussed extensively on nutrient and chlorophyll distributions and there has been limited study of primary productivity on isolated cruises covering small spatial and temporal scales. Very little is known about seasonal and interannual variability of primary productivity and the importance of different phytoplankton size fractions have not been investigated for the west coast of Vancouver Island.

Thesis Goals

Physical, chemical and biological parameters were investigated to document spatial and temporal variability in transects crossing the continental margin on the west coast of Vancouver Island. Specifically, during 1997 and 1998 the variability of physical, chemical and biological parameters was studied: a) for the shelf and beyond the shelf regions, b) for 4 distinct geographic regions of the west coast of Vancouver Island such as a region cut by a underwater canyon, or strongly affected by strong estuarine flow, and c) over the spring, summer and fall growing seasons. This thesis also evaluates the size structure of primary productivity and phytoplankton biomass. Primary productivity was examined in the upper water column on horizontal transects across the continental margin to document the spatial and temporal variability in the size distribution of phytoplankton. Three specific questions were addressed by this research:

(1) Do dissolved nutrients, chlorophyll concentrations and primary productivity vary seasonally, interannually and spatially?

(2) Does the large size fraction (>5.0 μm) contribute substantially to the phytoplankton biomass and primary productivity during the upwelling season?

(3) Was the primary productivity impacted during the strong ENSO event of 1997 and 1998?

Field studies were conducted as part of the Canadian GLOBEC program aboard the C.S.S "John P. Tully". Cruises off the west coast of Vancouver Island were undertaken seasonally over a period of two years from 1997-1999. The data for the 1999 cruises are contained in Appendices B (chlorophyll), C (nutrients), and D (primary productivity).

Thesis Organization

Chapter one of this thesis examines seasonal variability of physical, chemical and biological parameters along the west coast of Vancouver Island. Four transects perpendicular to the coast were studied in detail and the results will be discussed in Chapter one. The four transects were: over La Pérouse Bank, over Barkley Canyon, off Estevan Point, and off Brooks Peninsula. Chapter two examines size-fractionated biomass and primary productivity of the four study transects. At each transect, sampling stations were chosen in order to have one station on and one station off of the continental shelf.

CHAPTER 1

VARIABILITY OF PHYSICAL, CHEMICAL AND BIOLOGICAL PARAMETERS OFF THE WEST COAST OF VANCOUVER ISLAND

INTRODUCTION

The goal of GLOBEC was to determine how and why marine ecosystems change in response to variations in the physical oceanic environment. To quantify and interpret these changes on the continental margin of British Columbia, it is essential to expand upon existing time series observations, both temporally and spatially. Long-term time series data sets are necessary to achieve this goal because many of these changes are known to occur on interannual or decadal time scales (Dickson *et al.*, 1988; Beamish and Bouillan, 1993; Steele, 1998) which can only be identified and understood using multi-year data sets. It is essential to expand the time base of existing time series by incorporating new observations to allow identification of low frequency variability important to both physical and biological processes.

The southern margin of the west coast of Vancouver Island has been the focus of extensive studies but there has been little study of the northern coast of the Island. It is important to expand studies to the northern regions of Vancouver Island because previous studies have found strong upstream influences on water properties off the southwest coast of Vancouver Island (Thomson *et al.*, 1989).

In addition to the expansion of the time-series observations (this chapter), and process studies (Chapter 2), numerical ecosystem models are being developed that require boundary conditions and validation data and expansion of historical data sets will greatly increase confidence in the results of model predictions (Ianson *et al.*, submitted).

The main objective of this chapter was to show the seasonal, interannual and spatial variability of physical, chemical and biological parameters in transects that cross the continental margin off the west coast of Vancouver Island.

MATERIALS AND METHODS

Six cruises aboard the C.S.S. John P. Tully were undertaken on the west coast of Vancouver Island as part of the Canadian **Glob**al Ocean **Ec**osystem Dynamics program (GLOBEC). Studies were conducted during 3 cruises in 1997 and three in 1998, which correspond to the annual spring transition, the summer upwelling season and fall transition period. Cruise details are available in Table A.1. Studies were also conducted during 3 cruises in 1999 and these data are in Appendix B (dissolved nutrients), Appendix C (chlorophyll), and Appendix D (primary productivity). Studies were conducted at several stations along transects extending perpendicular to the west coast of Vancouver Island from the southern to the northern tip of Vancouver Island (Figure 1.1). These transects bisected the continental shelf, and the shelf break and ended in deep water beyond the shelf. An attempt was made to occupy similar stations during each cruise, but sampling logistics and weather conditions prohibited complete replication. During the spring transition cruise in April 1997, several stations were sampled again one week after the initial occupation. Station details such as latitude, longitude and water depth for all stations sampled during each of the 3 cruises in 1997, 3 cruises in 1998 and 3 cruises in 1999 are presented in Appendices E.

Physical Measurements

Incident surface solar irradiance (photosynthetically active radiation - I_o PAR) was continuously measured with a Licor Quantum Sensor Model LI-190SB calibrated for use in air

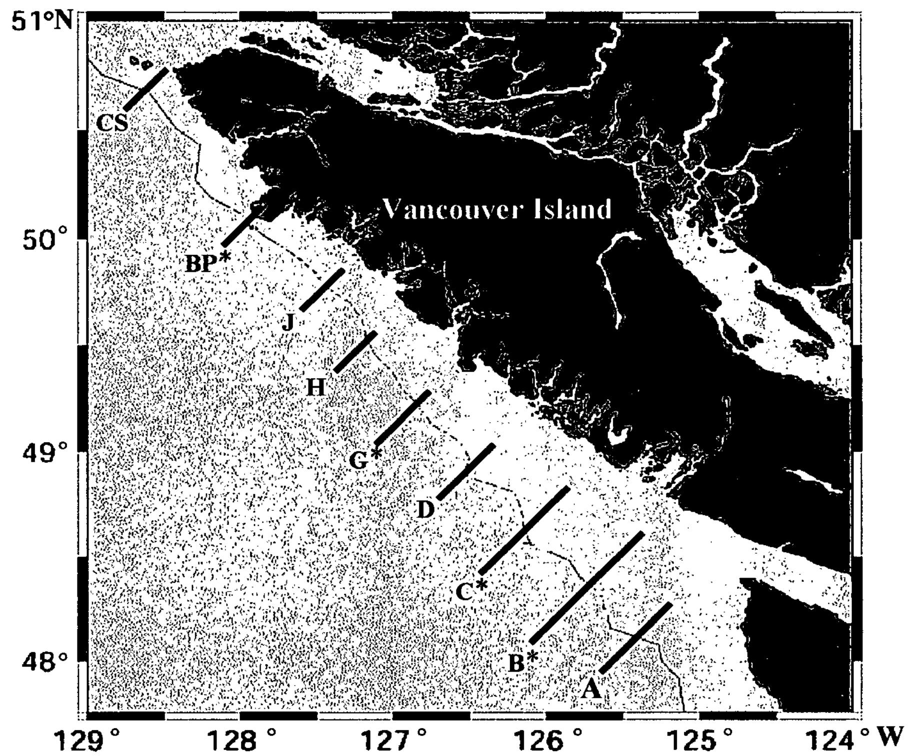

Figure 1.1 Location of transects off the west coast of Vancouver Island. Dashed line delineates the 200 m contour. A=Juan de Fuca Canyon (Line A), B=La Pérouse Bank (Line B), C=Barkley Canyon (Line C), D=D Line, G=Estevan Point (Line G), H=H Line, J=J Line, BP=Brooks Peninsula (BP Line) and CS=Cape Scott (CS Line). Transects with * will be discussed in this chapter.

and mounted in a shade-free area on the after-deck of the ship. The measurements were logged as 10 min averages using a Licor datalogger Model LI-1000. Light data were obtained for all cruises except the October 1998 cruise due to a datalogger failure; therefore for October 1998, primary productivity calculations the light data from October 1997 was used. In May 1998, the datalogger did not log continuously, and therefore for the days without continuous data, the data for a similar day was used.

Vertical profiles of underwater irradiance were measured with a Biospherical QSP-200 L4S 4495 PAR sensor calibrated for use in water. When light profiles could not be measured due to weather conditions, pre-dawn sampling, or unfavorable sampling logistics, estimates based on previous casts were used. For these stations, actual and estimated light depths may have been slightly different. Due to a processing error, underwater irradiance is not available for most stations at the time of writing.

Vertical profiles of conductivity, temperature, pressure, and chlorophyll fluorescence were obtained using a Seabird® Model SBE 911^{+} CTD Serial #0437 mounted with a SeaTech fluorometer. Personnel from the Institute of Ocean Sciences (Sidney, B.C.) provided all physical data. The raw data are stored at the Institute of Ocean Sciences.

Vertical profiles of σ_t were derived from temperature and salinity data using the expression given by Millero and Poisson (1981). The mixed layer depth was identified as the depth where a 0.125 change in σ_t was first observed relative to a surface reference value (after Levitus, 1982).

Chemical and Biological Measurements

The time of the day when stations were occupied was variable among stations and between cruises and was dependent upon the time of arrival on station. Seawater was collected using acid-cleaned 10-L PVC Niskin bottles equipped with Teflon® coated springs and fittings and silicone tubing mounted on an instrumented rosette sampler. Seawater samples for vertical profiles of chemical and biological parameters were taken at 0, 10, 20, 30, 50, 75, 100, 125, 150, 175, 200, 250, 300, 500, 600, 700, 800, 1000, 1200, 1400, 1500, 1600, 1700 m depending on the bottom depth. After collection of dissolved oxygen, water samples were immediately collected for dissolved nutrients, chlorophyll *a*, phytoplankton identification and primary productivity measurements (Chapter 2). Seawater was also collected for particulate nitrogen and carbon, ammonium and urea concentrations and nitrogen uptake rate experiments (Varela *et al.*, in prep.).

Water samples for nitrate + nitrite (NO_3^- + NO_2^-), soluble reactive phosphate (HPO_4^{2-}), and silicic acid ($Si(OH)_4$) were filtered directly out of the Niskin bottles using an acid-cleaned 60 ml Nalgene® syringe fitted with 25 mm Millipore Swinnex® filter holder and a combusted (460°C for 4.5 h) 25 mm glass-fibre filter. In 1997, seawater was filtered through 25 mm Whatman™ GF/F glass-fibre filters (nominal pore size 0.7 μm) and in 1998, 25 mm AMD™ GF75 glass-fibre filters (nominal pore size 0.75 μm) were used. Seawater was gently filtered into acid-cleaned Nalgene® bottles and stored at -20°C until analysis ashore. Gloves were used for all nutrient sampling to avoid contamination. All dissolved nutrients were processed using a Technicon® Autoanalyzer® II. Nitrate plus nitrite, soluble reactive phosphate and silicic acid were determined using the procedures of Wood *et al.* (1967), Hager *et al.* (1968), Armstrong *et al.* (1967), respectively. Combined nitrate and nitrite concentrations are reported as nitrate. Shelf region stations were east of the shelf break, as defined by the 200 m contour, and the beyond shelf stations were those beyond the shelf break. The number of stations varied at each transect and each cruise and are summarized in Appendix E.

Chlorophyll corrected for phaeopigments was determined at 0, 10, 20, 30, and 50 m water depth by *in vitro* fluorometry (Yentsch and Menzel, 1963). A 500 ml water sample was filtered onto 25 mm diameter glass-fibre filters using a vacuum pressure differential of <100 mm of Hg and stored at –20°C in a dark desiccator until analysis ashore. In 1997, seawater was filtered through 25 mm Whatman™ GF/F glass-fibre filters and in 1998, 25 mm AMD™ GF75 glass-fibre filters were used. All samples were analyzed within two weeks of collection. Chl *a* was extracted in 10 ml of 90% acetone by sonication in an ice bath for 10 min and then subsequently stored in the dark for 20-24 h at –20°C. The fluorescence of the acetone extract was measured before and after the addition of three drops of 10% HCl to estimate phaeopigments in a Turner Designs™ Model 10-AU fluorometer calibrated with a solution of commercially available chlorophyll *a* obtained from Sigma Chemical Company. Chlorophyll *a* calculated using the equation of Parsons *et al.* (1984).

Samples for phytoplankton identification were fixed with acidic Lugol's iodine solution during the 1997 sampling season and neutral Lugol's iodine solution during the 1998 sampling season (Throndsen, 1978; Parsons *et al.*, 1984). The samples were stored in the dark until identification and enumeration was performed using inverted microscopy following Utermöhl (1958) procedures. Depending on the biomass, 10 or 25 ml was settled in a counting chamber for at least 12 h. This methodology underestimated the heterotrophic crytomonads that would best be distinguished using an epifluorescence technique (Geider, 1988). The counts were then converted into cells l^{-1}. Cell carbon was calculated according to the equations of Strathman (1967). Cell volumes specific to each species were required for the conversion of cells l^{-1} to carbon. Cell volume calculated using measurements of representative cells and equations for simple geometric shapes spheroids, cylinders, boxes, and cones were supplied by R. Haigh (unpubl. data). The cell volume for each species is given in Appendix F.

Statistical analysis of chemical and biological data

Replicate casts were not completed due to time constraints in the cruise schedule and the labor-intensive nature of this study. Routinely a single water sample was collected from each depth for analysis of chemical and biological parameters.

One factor analysis of variance (ANOVA) and a Tukey test were used to examine spatial and temporal variation. For analysis of temporal variation, both interannual and seasonal, the physical, chemical and biological data were grouped according to mean values for the west coast of Vancouver Island (WCVI) and for shelf and beyond shelf regions. For analysis of spatial variation, the cross shelf and along shore direction, the data were grouped according to cruise and year.

Contour plots were created using Wavemetric Igor Pro (v. 4.0) using 64x triangulation.

RESULTS

I. Physical Parameters

A)Incident Irradiance

The continuous recordings of incident surface irradiance are shown for April, July and October of 1997 and May and July 1998 in Figure 1.2. Irradiance data are not available for October 1998 due to a datalogger malfunction. For the two study years, the highest values were observed in July 1997 (Figure 1.2b) and the lowest values in October 1997 (Figure 1.2c). For July 1997, surface irradiance was consistently high, and during October 1997, surface irradiance was consistently low for the duration of the cruise. There was considerable variability in surface irradiance during May and July of 1998 (Figure 1.2 D & E) while incident surface irradiance in April and July of 1997 was more consistent.

The incident solar irradiance on the day of the primary productivity experiments (Chapter 2) is included in Appendix G. Included in the plots is the percentage that the incubation period represented of the total daily irradiance.

B) Mixed Layer Parameters (Depth, temperature, salinity and σ_t)

Very high variability of mixed layer parameters was measured off the west coast of Vancouver Island, and frequently the standard deviation and mean were similar. Trends and patterns will be discussed, but the differences between regions, cruises or years are not statistically significant unless otherwise noted.

Mixed layer (ML) depth and mixed layer parameters are shown in Table 1.1 for April, July and October 1997 and Table 1.2 for May, July and October 1998 for the primary productivity stations.

B1) MIXED LAYER (ML) DEPTH

The ML was consistently deeper at beyond shelf regions than those over the shelf. On average over the 2 years, the ML was 23 ±12 m in the beyond shelf region and 12 ±6 m in the shelf region. The ML was deeper in 1998 compared to 1997 for both the shelf and the beyond shelf region. The mean ML in the shelf region was 11 ±7 m in 1997 and was 13 ±5 m in 1998 and for the beyond shelf region was 22 ±19 m in 1997 and 24 ±6 m in 1998.

There was a consistent seasonal pattern for the shelf region in 1997 and 1998. The ML was deepest in October and shallowest during July, the month of continuously high surface irradiance. There was no consistent seasonal pattern for the beyond shelf region in 1997 and 1998. In 1997 the deepest ML was in April, and in 1998 was in October.

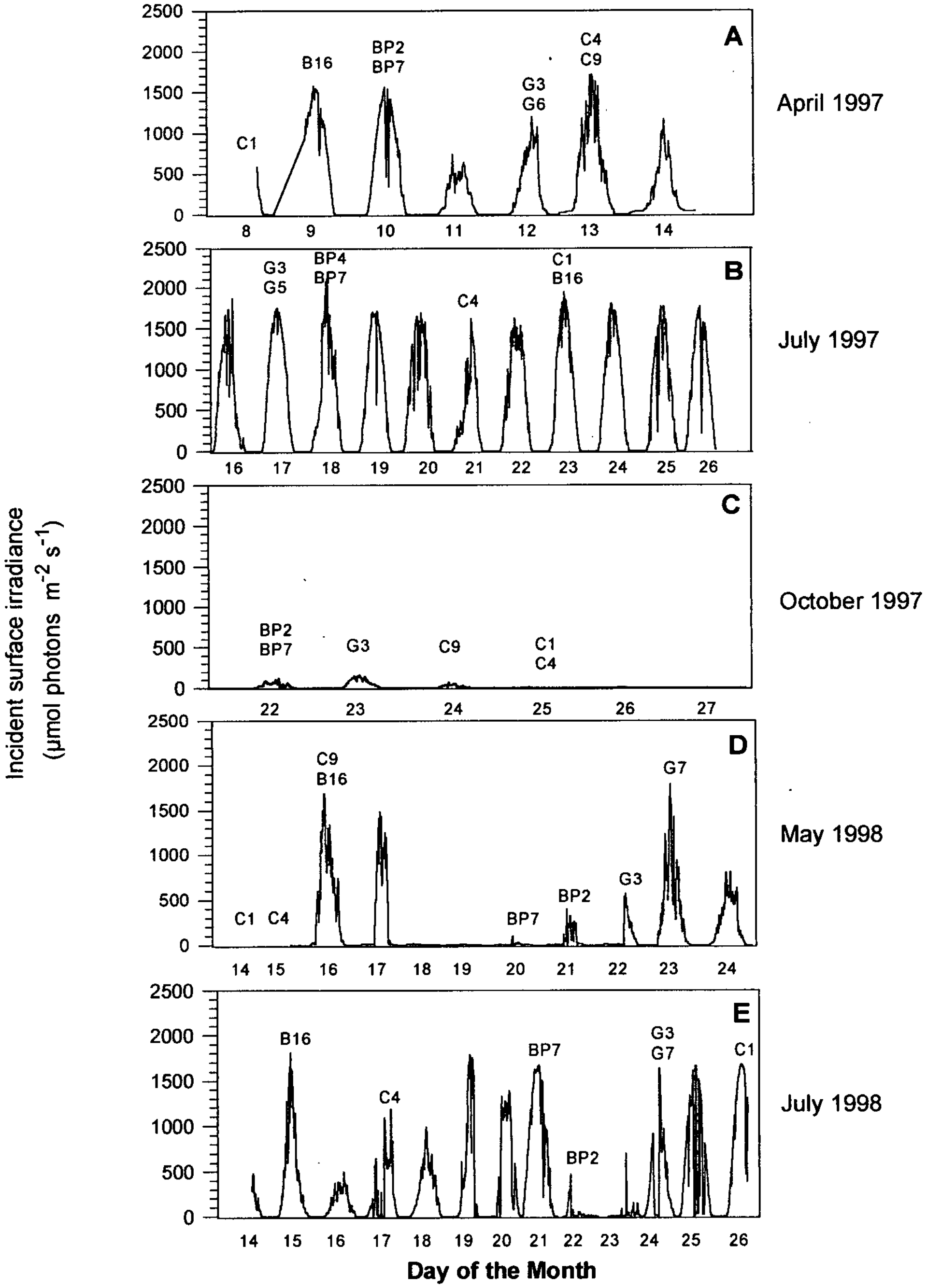

Figure 1.2 Incident surface irradiance for A) April 1997, B) July 1997, C) October 1997, D) May 1998 and E) July 1998. Station labels on top of peaks indicate day primary productivity was measured. See Appendix E for location of stations. Irradiance data are not available for October 1998.

No consistent south-north trend was observed in mixed layer depth at shelf or beyond shelf stations. Vertical profiles of temperature, salinity and σ_t for the primary productivity stations are provided in Appendix H. Variability was higher in 1997 than in 1998 for the shelf and the beyond shelf region (see coefficient of variation in Tables 1.2 and 1.3). Seasonal variability was highest in July for both the shelf and the beyond shelf region.

B2) ML TEMPERATURES

ML temperatures were on average warmer (~ 1°C) at the beyond shelf region than at the shelf regions. On average over the 2 years, the ML temperature was 12.8 ±2.1°C in the beyond shelf region and 11.9 ±1.7°C in the shelf region. The ML temperature in the shelf region were similar in 1997 and in 1998, while in the beyond shelf region ML temperatures were on average warmer in 1998 than in 1997. In 1997, the spring cruise was approximately one month earlier than the spring cruise in 1998, this might explain the lower temperature measured in 1997. If spring cruise is not include in the seasonal mean, the is no significant difference between 1997 (14.1°C) and 1998 (13.9°C).

There was a consistent seasonal pattern for the shelf region and the beyond shelf region in 1997 and 1998. The ML temperatures in the shelf region were warmest in July and coolest in April. The water column was generally weakly stratified during April 1997 but was stratified by July. In July, the thermocline was ~10 m, but by October it was depressed to ~40 m (Appendices, H1-H3). In 1998, the water column was generally strongly stratified for all cruises; the thermocline was ~20-30 m in the beyond shelf region and ~10-20 m for shelf regions (Appendices, H4-H6). In 1997, the seasonal variability in the ML temperature in the shelf region was significant ($p<0.01$), while in 1998 no significant seasonal variability was found. The seasonal variability in the ML temperature of the beyond shelf region was significant during both study years ($p<0.01$).

A consistent alongshore trend in ML temperature was not observed for the shelf region while a consistent trend was observed for the beyond shelf region. Beyond shelf stations of the southern transects La Pérouse Bank or Barkley Canyon tended to be warmer than the northern transects, Estevan Point and Brooks Peninsula. The northern transects have shorter continental shelves so upwelled water has less distance and less time to warm before it is transported to the beyond shelf region. In contrast, by the time cold upwelled water arrives at the beyond shelf stations of the southern transects, solar irradiation has warmed it.

Low ML temperatures corresponded to high salinity measurements, consistent with characteristics of an upwelling region. Similarly, at stations with high ML temperature, the lowest salinity was noted.

Variability was higher in 1997 than in 1998 for the shelf and the beyond shelf region (see coefficient of variation in Tables 1.2 and 1.3). Variability was highest in October for both the shelf and the beyond shelf region in 1997 and 1998. ML temperatures ranged from 9.0-17.5°C during 1997 and 10.3–14.6°C during 1998.

B3) ML SALINITY AND DENSITY

The ML salinity and density were on average lower in shelf regions than at the beyond shelf regions. On average over the 2 years, the ML salinity was 31.5 ±0.7 in the beyond shelf region and 31.1 ±0.9 in the shelf region. The ML salinity and density in the shelf region and beyond shelf region were lower in 1997 than in 1998. The lowest ML salinity and density was measured in the shelf region in 1997.

There was no consistent seasonal trend in ML salinity and density in the shelf region. Salinity and density tended to be lowest in April suggesting the VICC lowered the salinity, but by July and October the salinity increased perhaps due to upwelling. There was no consistent seasonal trend for the beyond shelf regions.

No consistent south-north (latitudinal) trend was observed at either shelf or beyond shelf stations during either 1997 or 1998. The transect that showed the highest and the lowest salinity and density, varied during each cruise.

Variability in salinity and density was low during 1997 and 1998, but was higher in 1997 than in 1998 for both shelf and the beyond shelf regions (see coefficient of variation in Tables 1.2 and 1.3). Variability was similar during each cruise for both the shelf and the beyond shelf regions in 1997 and 1998. ML salinity ranged from 29.18-32.38 during 1997 and 30.99 – 32.35 during 1998.

B4) SUMMARY OF PHYSICAL PARAMETERS

In summary, a strong seasonal cycle was noted for solar radiation, the highest flux was measured in July and the lowest during October. A shoaling in the mixed layer depth was noted in both regions in 1997 relative to 1998. Mixed layer temperature was similar in both years. Salinity and density were lower in 1997 than in 1998 for both regions. A strong cross-shelf gradient was observed in 1997 and 1998. The mixed layer depth was consistently deeper and temperature, salinity and density were all higher in the beyond shelf regions than in the shelf region.

Table 1.1 Mixed layer parameters for stations occupied during 1997 cruises off the west coast of Vancouver Island (WCVI). Monthly mean, yearly mean ± 1 S.D. and yearly coefficient of variation, (C.V.,%) are given for the shelf and beyond shelf region. Temperature (°C), salinity, and density for the mixed layer were calculated as the mean value from the surface to the calculated mixed layer depth. Dashed line indicates that data are not available.

Transect	Date	Mixed Layer (m)	Temp. (°C)	Salinity	Density (σ_t)
Shelf					
La Pérouse Bank	April	3	9.16	29.39	22.73
	July	3	11.6	31.70	24.17
	Oct.	25	10.9	31.45	24.07
Barkley Canyon	April	17	9.70	29.18	22.48
	July	10	14.3	30.81	22.92
	Oct.	14	14.0	31.13	23.23
Estevan Point	April	14	9.16	30.40	23.52
	July	9	15.1	30.16	22.26
	Oct.	16	14.0	30.59	22.84
Brooks Peninsula	April	5	8.97	29.46	22.51
	July	6	11.9	31.41	23.84
	Oct.	7	13.5	29.98	22.44
WCVI	April	10	9.2	29.6	22.8
WCVI	July	7	13.2	31.0	23.3
WCVI	Oct.	16	13.1	30.8	22.9
WCVI	1997	11	11.9	30.47	23.00
SD	1997	6.6	2.3	0.9	0.7
CV	1997	62	19	3	3
Beyond Shelf					
La Pérouse Bank	April	67	8.67	32.38	25.15
	July	13	17.5	30.78	22.20
	Oct.	-	-	-	-
Barkley Canyon	April	11	9.23	31.28	24.20
	July	-	-	-	-
	Oct.	19	13.5	31.01	23.24
Estevan Point	April	15	9.06	30.15	23.34
	July	9	14.9	30.20	22.33
	Oct.	38	12.9	31.92	24.04
Brooks Peninsula	April	-	-	-	-
	July	14	13.0	31.10	23.40
	Oct.	12	13.2	30.36	22.80
WCVI	April	31	9	31.3	24.2
WCVI	July	12	15.0	30.7	22.6
WCVI	Oct.	23	13.2	31.1	23.4
WCVI	1997	22	12.4	31.0	23.4
SD	1997	19.0	2.9	0.8	0.9
CV	1997	86	24	2	4

Latitude, longitude and bottom depth are found in Appendix E.

Table 1.2 Mixed layer parameters for stations occupied during 1998 cruises off the west coast of Vancouver Island (WCVI). Monthly mean, yearly mean ± 1 S.D. and yearly coefficient of variation (C.V., %) are given for the shelf and beyond shelf region. Temperature (°C), salinity, and density for the mixed layer were calculated as the mean value from the surface to the calculated mixed layer depth.

Transect	Date	Mixed Layer (m)	Temp. (°C)	Salinity	Density (σ_t)
Shelf					
La Pérouse Bank	April	19	10.3	30.99	23.81
	July	8	11.9	32.27	24.51
	Oct.	11	12.2	32.10	24.34
Barkley Canyon	April	10	11.9	31.16	23.66
	July	9	12.1	31.89	24.18
	Oct.	19	11.5	32.30	24.61
Estevan Point	April	19	12.4	31.49	23.83
	July	15	13.4	31.27	23.46
	Oct.	16	11.8	31.97	24.30
Brooks Peninsula	April	8	11.0	31.79	24.31
	July	11	12.9	31.44	23.68
	Oct.	9	11.4	31.79	24.23
WCVI	April	15	11.4	31.4	23.9
WCVI	July	11	12.6	31.7	24.0
WCVI	Oct.	14	11.7	32.0	24.4
WCVI	1997	13	11.9	31.7	24.1
SD	1997	5	0.8	0.4	0.4
CV	1997	35	7	1	2
Beyond Shelf					
La Pérouse Bank	April	23	11.6	31.91	24.34
	July	26	14.6	32.35	24.04
	Oct.	37	13.8	32.13	24.04
Barkley Canyon	April	16	11.9	31.64	24.02
	July	23	13.9	32.10	23.98
	Oct.	31	14.5	32.22	23.96
Estevan Point	April	22	11.4	31.97	24.37
	July	31	14.4	32.05	23.86
	Oct.	23	13.6	32.15	24.08
Brooks Peninsula	April	21	10.6	31.90	24.45
	July	25	13.6	31.94	23.93
	Oct.	15	13.0	32.19	24.24
WCVI	April	21	11.4	31.9	24.3
WCVI	July	26	14.1	32.1	24.0
WCVI	Oct.	27	13.7	32.2	24.1
WCVI	1997	24	13.1	32.0	24.1
SD	1997	6.3	1.3	0.2	0.2
CV	1997	26	10	1	1

Latitude, longitude and bottom depth are found in Appendix E.

II. Chemical Parameters

The following sections will examine the distribution of surface (0-10 m) nutrients in space and time. All values that will be discussed are 0-10 m surface concentrations. Vertical profiles of all three nutrients are provided in Appendix I.

For the nutrient data, three spatial scales were examined: the mean of all stations sampled, including all shelf and the beyond shelf stations, will be referred to as the mean for the WCVI; a cross-shelf gradient (east/west) and for the nutrient data is referred to as $NO_3^-{}_{shelf}$, $HPO_4^{2-}{}_{shelf}$, $Si(OH)_{4shelf}$ or $NO_3^-{}_{beyond}$, $HPO_4^{2-}{}_{beyond}$ or $Si(OH)_{4beyond}$ for each transect; and in an alongshore gradient (latitudinal gradient) from the southern La Pérouse transect to the northern Brooks Peninsula transect for the shelf and beyond shelf region. Three time scales will be examined for each spatial scale: a 2-yr mean (1997 and 1998); annual mean for 1997 and 1998; and season means.

Very high variability was measured off the west coast of Vancouver Island, and frequently the standard deviation and mean were similar. Trends and patterns will be discussed, but the differences between regions, cruises or years are not statistically significant unless otherwise noted.

A) DISSOLVED NUTRIENT CONCENTRATIONS

A1) MEAN VALUES FOR THE WCVI

The average $WCVI_{nitrate}$, $WCVI_{phosphate}$, $WCVI_{silicic\ acid}$ are shown in Table 1.3. The 2-yr mean $WCVI_{nitrate}$ was 4.1 μM, $WCVI_{phosphate}$ was 0.59 and $WCVI_{silicic\ acid}$ was 10.5 μM. $WCVI_{nitrate}$ in 1997 was 5.2 μM and in 1998 it was 2.9 μM, which was significantly lower than in 1997 ($p<0.05$). The $WVCI_{phosphate}$ in 1997 was 0.55 μM and in 1998 it was 0.63 μM. The $WCVI_{silicic\ acid}$ concentration in 1997 was 12.9 μM and in 1998 was 8.12 μM, which were significantly lower than in 1997 ($p<0.01$).

A seasonal trend was evident in 1997 for $WCVI_{nitrate}$ and $WCVI_{silicic\ acid}$ but not for $WVCI_{phosphate.}$ On average in 1997, $WCVI_{nitrate}$ and $WCVI_{silicic\ acid}$ concentrations were highest in April and decreased as the season progressed to the lowest during October. In 1998, nutrients were consistently high in October and there was a significant difference in nitrate ($p<0.05$), phosphate ($p<0.05$), and silicic acid ($p<0.01$) concentration between cruises in 1998.

In April 1997, surface (0-10 m) NO_3^- ranged from 2.5-13.5 µM, HPO_4^{2-} ranged from 0.3-1.0 µM, and $Si(OH)_4$ ranged from 11.2-29.2 µM. Variability was consistently higher in 1998 than in 1997 for nitrate, phosphate and silicic acid.

Table 1.3 Mean nutrient concentrations (0-10m) (µM) for WCVI during each cruise in 1997 and 1998. Values are the mean of all stations during each cruise. Yearly mean ±1 S.D. and coefficient of variation (CV, %) are included.

	NO_3^-	HPO_4^{2-}	$Si(OH)_4$
1997 April	6.6 ±2.1	0.5±0.1	15 ±3.4
July	6.4 ±5.4	0.6 ±0.4	13 ±9.8
Oct.	3.3 ±2.3	0.6 ±0.2	11 ±3.4
1997 Mean	5.4 ±4.0	0.6 ±0.3	13 ±6.8
1997 CV	47	28	28
1998 May	0.9 ±1.1	0.3 ±0.1	2.7 ±1.5
July	3.4 ±3.6	0.8 ±0.3	10 ±5.5
Oct.	5.1 ±2.8	0.8 ±0.4	9.8 ±6.0
1998 Mean	3.1 ±3.3	0.6 ±0.4	7.0 ±5.9
1998 CV	91	40	52
2 year	4.4 ±3.8	0.6 ±0.3	11 ±7.0
2 year CV	86	56	65

A2) CROSS-SHELF GRADIENT

The mean nutrient concentrations are shown for each cruise in 1997 and 1998 in Table 1.4. Note that during 1998 there was no data available for La Pérouse Bank. On average nutrient concentrations were all higher in the shelf region than in the beyond shelf region. In 1997, nutrient concentrations in the shelf region were all significantly higher than in the beyond shelf region. In 1998, phosphate and silicic acid were significantly higher, while nitrate was not ($p>0.05$). Nutrient concentrations were higher in 1997 than in 1998, but the differences were significant only for nitrate and silicic acid ($p<0.05$).

Generally as the distance from shore increased, the nutrient concentrations decreased (Figure 1.3-1.5) and in many instances the decreasing concentrations are observed after the shelf break. In April 1997, nutient concentrations did not reach detection limits, while in July and October nutrient concentrations were observed at detection limits in the beyond shelf region. The most obvious feature in 1998 was that NO_3^- and HPO_4^{2-} concentrations at many transects were generally at or below detection limits in the shelf and beyond shelf regions during the May cruise and these were the lowest concentrations that were measured for all three nutrients during the two study years. In July 1998, surface nutrients in the shelf region were higher than in May, but nutrient concentrations decreased to detection limits as the distance from shore increased. The same pattern was observed in October 1998.

There was no consistent seasonal trend for nitrate, phosphate or silicic acid for shelf or beyond shelf regions in 1997 or 1998. The month during which maximum concentrations were measured, varied between region and between years. One consistent trend was clear; on average, the lowest nutrient concentration over the two years was in May 1998.

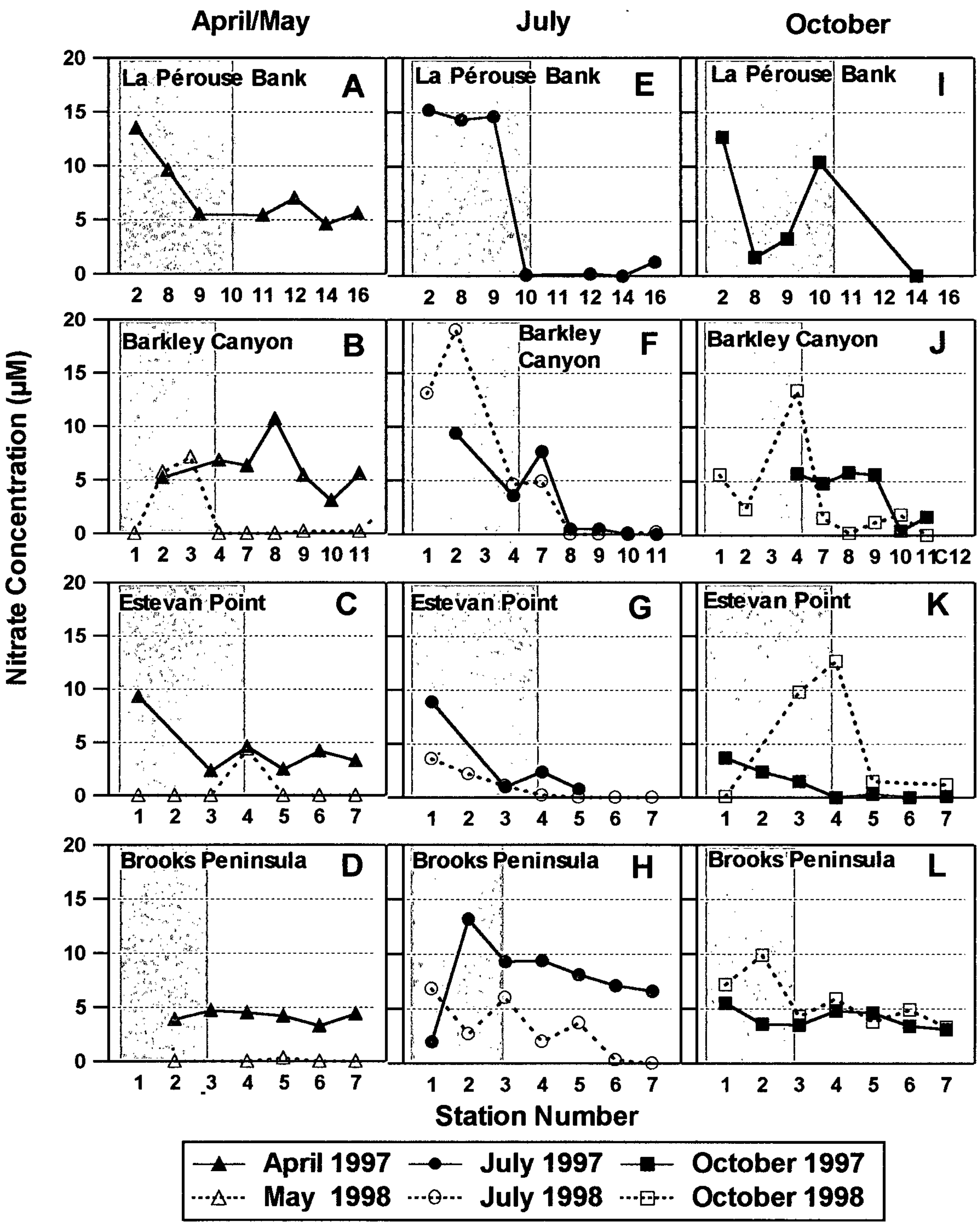

Figure 1.3 Surface (0-10m) nitrate concentration for all cruises in 1997 and 1998 along transects on La Pérouse Bank (Line B), Barkley Canyon (Line C), Estevan Point (Line G) and Brooks Peninsula (Line BP) off the west coast of Vancouver Island. Shaded area represents the shelf region; solid lines and closed symbols are for 1997 and dashed lines and open symbols are for 1998. No data are available for La Pérouse Bank in 1998. The distance offshore increases as the station number increases.

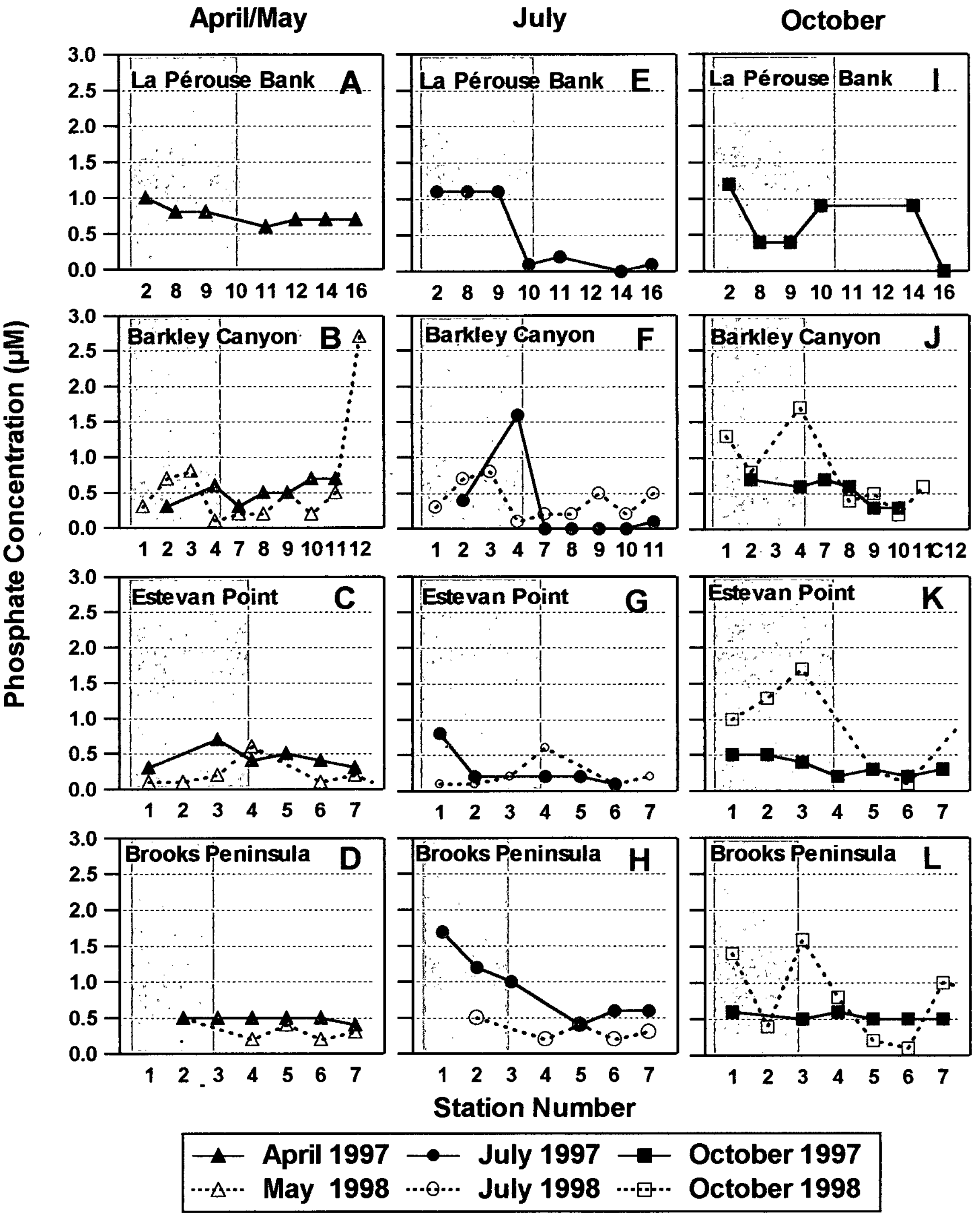

Figure 1.4 Surface (0-10m) phosphate concentration for all cruises in 1997 and 1998 along transects on La Pérouse Bank (Line B), Barkley Canyon (Line C), Estevan Point (Line G) and Brooks Peninsula (Line BP) off the west coast of Vancouver Island. Shaded area represents the shelf region; solid lines and closed symbols are for 1997 and dashed lines and open symbols are for 1998. No data are available for La Pérouse Bank in 1998. The distance offshore increases as the station number increases.

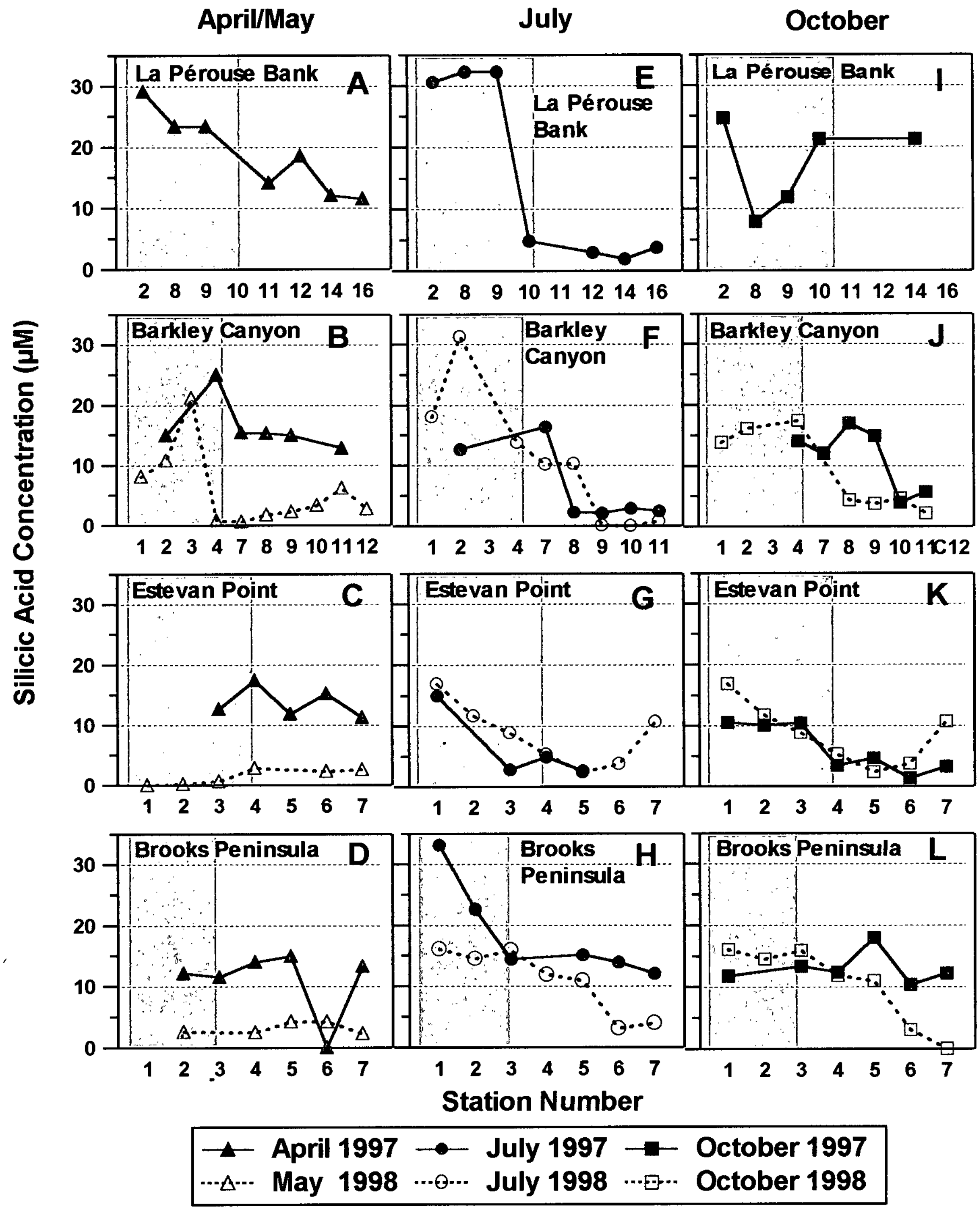

Figure 1.5 Surface (0-10m) silicic acid concentration for all cruises in 1997 and 1998 along transects on La Pérouse Bank (Line B), Barkley Canyon (Line C), Estevan Point (Line G) and Brooks Peninsula (Line BP) off the west coast of Vancouver Island. Shaded area represents the shelf region; solid lines and closed symbols are for 1997 and dashed lines and open symbols are for 1998. No data are available for La Pérouse Bank in 1998. The distance offshore increases as the station number increases.

Variability was high for all nutrient concentrations in both the shelf and beyond shelf region. In 1997, variability was highest in the beyond shelf region for all nutrients. In 1998 the region with the highest variability depended on the kind of nutrient. Nitrate was more variable in the beyond shelf region, while phosphate and silicic acid were more variable in the shelf region (Table 1.4). In general, variability was higher in 1998 than in 1997.

A3) NORTH- SOUTH GRADIENT

There was no consistent north/south gradient in nutrient concentrations in the shelf region or in the beyond shelf region for 1997 or for 1998. For shelf regions, the highest concentrations were generally measured over La Pérouse Bank in 1997 while in 1998, the location of peak concentrations was variable for each cruise and for each nutrient. For 1997, there was a weak trend for nitrate to decrease north from La Pérouse Bank to Estevan Point, then increase again at Brooks Peninsula.

A4) SUMMARY OF NUTRIENT CONCENTRATIONS

In summary, significantly higher nitrate and silicic acid concentrations were measured in 1997 than in 1998, but phosphate concentrations were similar for both years. Nutrient concentrations were higher in shelf regions than beyond shelf regions for both years. Generally, the highest nutrient concentrations were measured on La Pérouse Bank but on occasion, higher concentrations were measured at Brooks Peninsula. In May and July 1998, surface nitrate concentrations were frequently at or near detection limits suggesting either a lower nutrient supply rate or greater nitrate utilization in 1998 compared to 1997.

Table 1.4. Mean surface (0-10 m) nitrate, phosphate and silicic acid concentrations (μM) in 1997 and 1998 for shelf and beyond shelf stations of La Pérouse Bank, Barkley Canyon, Estevan Point, Brooks Peninsula off the west coast of Vancouver Island. The mean ± 1 S.D. and coefficient of variation (CV, %) for each year and for the 2 year average are given. The number of samples (n) for each transect is given. ND indicates nutrient concentration was not detectable. (-) indicates information not available. * indicates a significant difference between shelf and beyond shelf regions was found at p<0.05 level and ¤ indicates a significant difference between region was found at p<0.01 level.

Region	Nitrate		Phosphate		Silicic Acid		n	
	Shelf	Beyond	Shelf	Beyond	Shelf	Beyond	Shelf	Beyond
April 1997								
La Pérouse Bank	9.5	5.7	0.8	0.7	22	14	3	4
Barkley Canyon	6.1	6.5	0.4	0.6	18	14	3	3
Estevan Point	5.4	3.3	0.5	0.3	15	16	3	3
Brooks Peninsula	8.8	4.1	0.5	0.5	14	11	2	4
April WCVI mean	7.5	4.9	0.6	0.5	18	13.0	∑11	∑14
July 1997								
La Pérouse Bank	14.7	0.3	1.1	0.1	31	3	3	4
Barkley Canyon	6.9	0.5	0.9	0.1	18	3	3	4
Estevan Point	5.0	1.6	0.5	0.2	9	4	2	2
Brooks Peninsula	14.2	7.8	1.3	0.6	23	45	3	4
July WCVI mean	10.2	2.6	0.6	0.3	20.2	6.0	∑11	∑14
October 1997								
La Pérouse Bank	7.1	ND	0.7	0.7	15	12	3	2
Barkley Canyon	5.3	3.4	0.7	0.5	13	10	2	4
Estevan Point	2.5	0.1	0.5	0.2	10	3.0	3	4
Brooks Peninsula	4.2	3.8	0.6	0.5	14	12	3	3
Oct. WCVI mean	4.8	1.8	0.6	0.5	13.1	9.2	∑11	∑13
1997 Mean	¤7.5 ±3.8	¤3.1 ±2.7	¤0.7 ±0.3	¤0.4 ±0.2	¤17 ±6.2	¤9.4 ±4.8	33	41
1997 CV	50	56	39	54	36	51		
May 1998								
Barkley Canyon	3.2	0.8	0.3	0.4	5.08	3.4	4	4
Estevan Point	ND	1.1	0.1	0.4	0.27	2.0	3	4
Brooks Peninsula	0.3	0.05	0.5	0.3	2.6	3.0	1	6
WCVI mean	1.2	0.7	0.2	0.3	2.7	2.8	∑8	∑14
July 1998								
Barkley Canyon	10	0.1	1.3	0.5	18	2.8	4	4
Estevan Point	2.3	0.1	0.8	0.6	12	5.6	3	4
Brooks Peninsula	5.2	2.2	1.1	0.5	16	7.5	3	4
WCVI mean	6.0	0.8	1.1	0.5	15	5.3	∑10	∑12
October 1998								
Barkley Canyon	3.3	0.8	1.1	0.4	16	3.8	4	4
Estevan Point	9.5	5.1	1.5	0.2	-	-	2	3
Brooks Peninsula	7.1	4.5	1.0	0.6	-	-	3	4
WCVI mean	6.6	3.5	1.2	0.4	16	3.8	∑9	∑11
1998 Mean	4.6±3.8	1.6±1.9	*0.9±0.5	* 0.4±0.1	*10±7.4	*4.0±1.9	27	37
1998 CV	82	117	55	31	72	47		
2 year Mean	*6.1± 2.7	*2.4 ±1.5	0.8 ±0.3	0.4 ±0.1	14 ±5.5	6.6 ±3.5		
2 year CV	45	62	47	22	39	52		

III. Biological Parameters (Chlorophyll and phytoplankton species composition)

A) CHLOROPHYLL

For all cruises in 1998, no data are available for the La Pérouse transect due to time constraints and sampling logistics.

A1) MEAN VALUE FOR WEST COAST OF VANCOUVER ISLAND

The 2 yr average off the west coast of Vancouver Island was 77.2 ±55.4 mg chl m^{-2} (Table 1.5). On average, biomass was significantly higher in 1998 than in 1997 ($p<0.05$). In 1998, biomass was 1.6-fold higher than biomass measured for 1997.

There was a consistent seasonal peak in July in 1997 and 1998 but the increase in July was more obvious in 1998 than in 1997 (Figure 1.6). Variability was high off the west coast of Vancouver Island but was lower for 1997 than for 1998 (see coefficient of variation in Table 1.5); during both years the highest variability was measured in July.

Table 1.5 Mean chlorophyll (100-1% surface light) ±1 S.D. (mg chl m^{-2}) for WCVI during each cruise in 1997 and 1998. Values are the mean of all stations during each cruise. Yearly mean ±1 S.D. and coefficient of variation (CV, %) are included.

		Chlorophyll
1997		
	April	56.3 ±26.4 (23)
	July	77.1 ±55.2 (24)
	Oct.	47.4 ±17.7 (26)
1997	Mean	60.2 ±37.4 (73)
1997	CV	62
1998		
	May	67.6 ±32.8 (24)
	July	149 ±87.1 (19)
	Oct.	82.9 ±48.9 (21)
1998	Mean	99.9 ±67.6 (65)
1998	CV	68
97/98 Mean		77.2 ±55.4 72

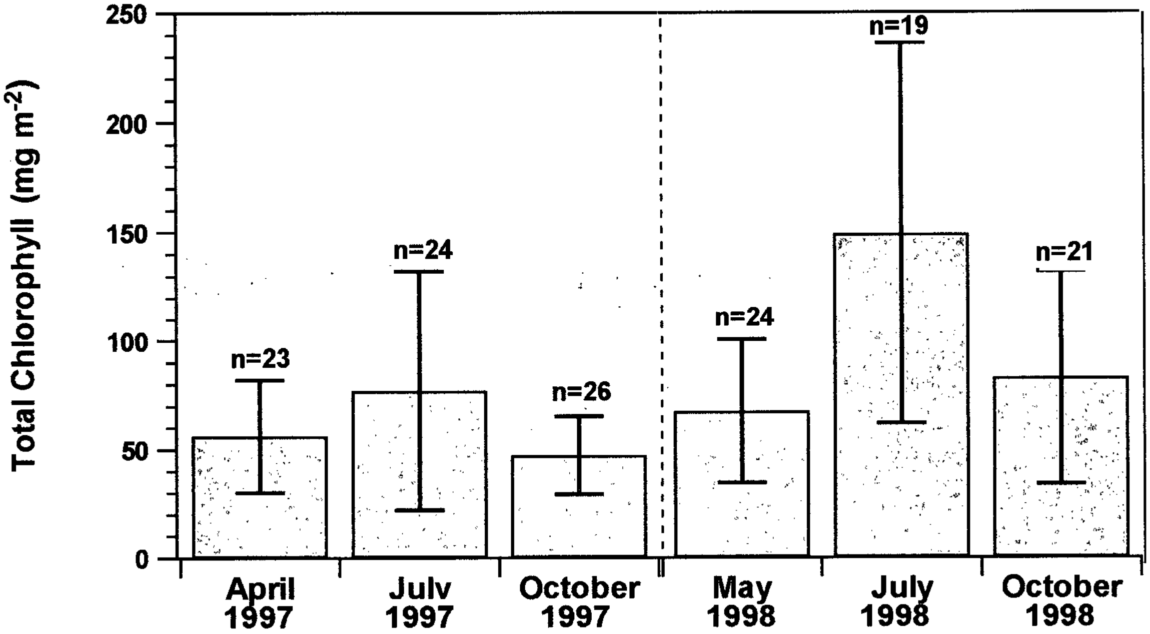

Figure 1.6 Total chlorophyll ± 1 S.D. off the west coast of Vancouver Island in 1997 and 1998. Values are the mean of shelf and beyond shelf stations during each cruise.

A2) CROSS-SHELF GRADIENT

2 yr and annual means

The biomass in shelf regions was on average 2-fold higher than in the beyond shelf regions (Figure 1.7). These plots clearly show higher chlorophyll in the shelf region. The 2 yr average chlorophyll concentration was 101 ±62.9 and 54.0 ±34.7 mg chl m^{-2} for shelf and beyond shelf regions, respectively (Table 1.6). On average, chlorophyll was significantly higher in the shelf than in the beyond shelf region in 1997 ($p<0.05$) and in 1998 ($p<0.05$). The biomass in the shelf region was significantly higher in 1998 compared to the biomass in the shelf region in 1997 ($p<0.05$). In the beyond shelf region there was little difference between years.

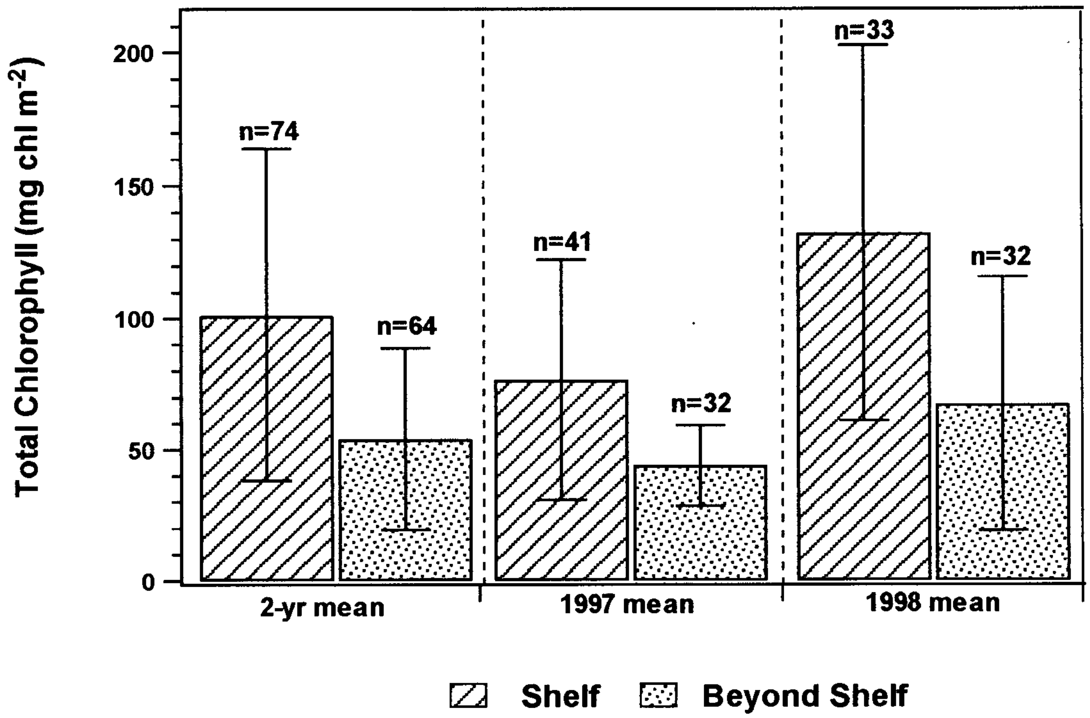

Figure 1.7 Interannual mean and annual means of total chlorophyll ± 1 S.D. of the shelf and the beyond shelf regions off the west coast of Vancouver Island in 1997 and 1998. Shelf and beyond shelf means are the mean of all shelf and beyond shelf stations sampled. Numbers above each bar are the total number of stations for each mean.

Seasonal variation

Generally, a consistent seasonal pattern was observed in the shelf regions in 1997 and 1998 (Figure 1.8). Biomass was consistently high in July during each year, but the increase in 1998 (2.0-fold) was larger than in 1997 (1.4-fold). Very high increases in biomass in the shelf region from April to July were observed. For example, at one station in 1998 biomass at Barkley Canyon increased almost 500% from April to July. In 1998, the biomass in July was significantly higher than May and October ($p<0.05$), but there was no significant difference between May and October (Tukey test, $p>0.05$).

The seasonal dynamics of biomass in the beyond shelf region were different relative to the shelf region. Biomass in the beyond shelf region showed little seasonal change during cruises in 1997, while in 1998 considerable seasonal variation was observed. In 1998, biomass peaked in July.

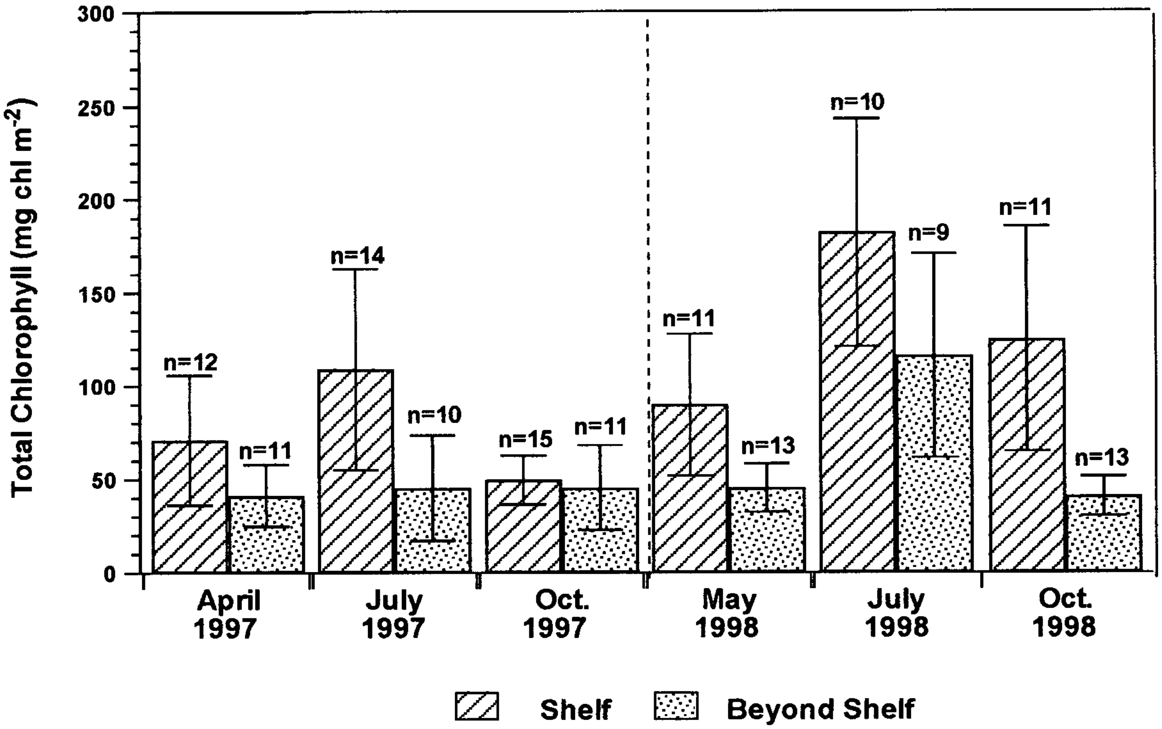

Figure 1.8 Seasonal variability of total chlorophyll ± 1 S.D. of the shelf and the beyond shelf regions off the west coast of Vancouver Island in 1997 and 1998. Shelf and beyond shelf means are the mean of all shelf and beyond shelf station during each cruise. Numbers above each bar = the total number of station.

Transects

Figure 1.9 shows how integrated chlorophyll varies as distance from shore increases. Generally, biomass decreases as the distance from shore increases. A striking feature noteworthy in Figure 1.9 was that peaks in biomass were generally observed in 1998 rather than in 1997, specifically for July 1998. In addition, the maximum biomass measured in 1998 was higher than in 1997. For 1998 the maximum Chl *a* was 428 mg chl m^{-2} in the shelf region of Estevan Point (Figure 1.9 G), whereas in 1997, the maximum biomass was 380 mg chl m^{-2} for the shelf region of La Pérouse Bank (Figure 1.9 E). It should be noted that the July 1998 cruise

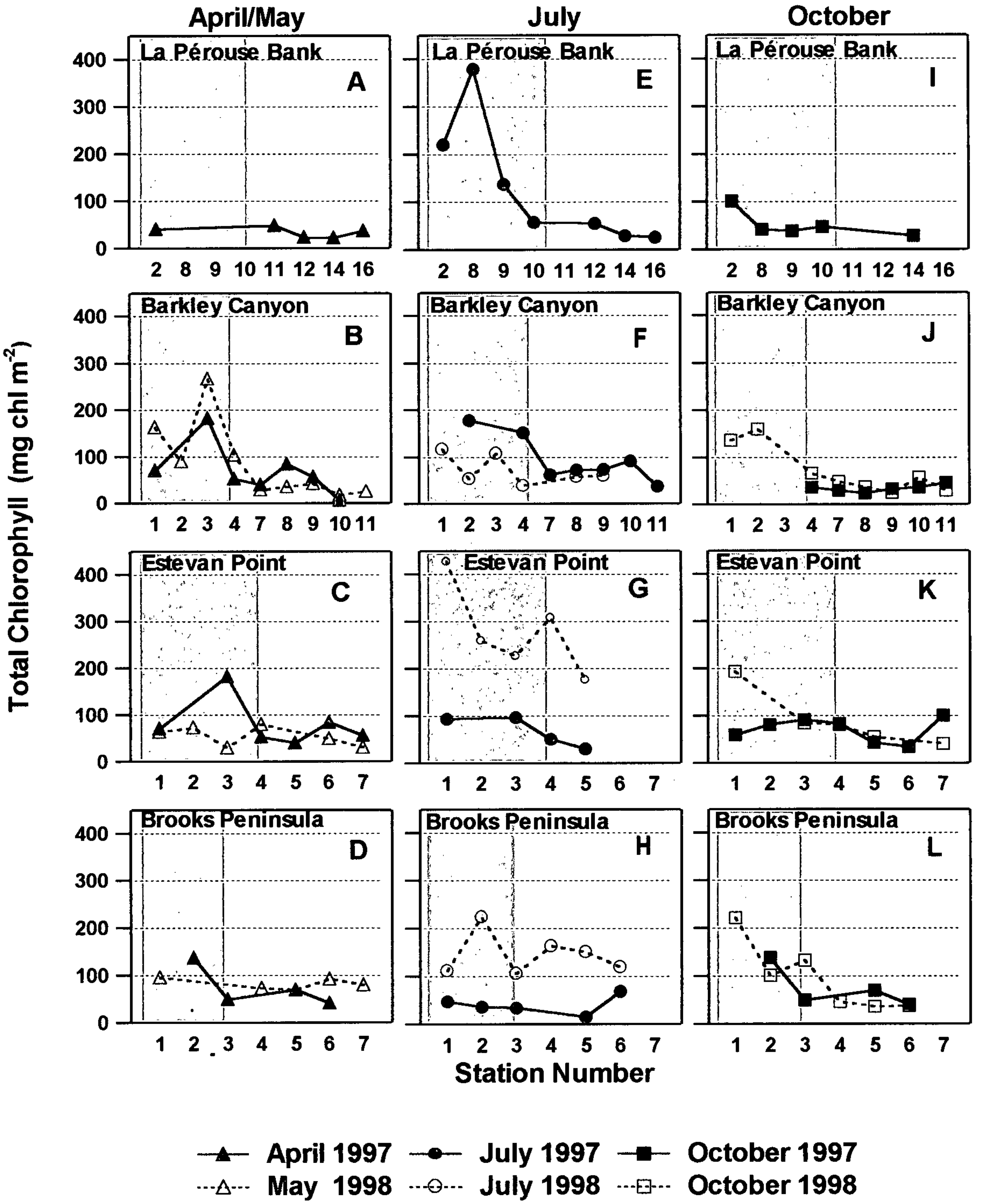

Figure 1.9 Integrated chlorophyll (mg chl m^{-2}) for all cruises in 1997 and 1998 along transects on La Pérouse Bank (Line B), Barkley Canyon (Line C), Estevan Point (Line G) and Brooks Peninsula (Line BP) on the west coast of Vancouver Island. Shaded area represents shelf region; solid lines and closed symbols are for 1997 and dashed lines and open symbols are for 1998. No data are available for La Pérouse Bank in 1998. The distance offshore increases as the station number increases.

was the only cruise in the two year sampling program that had consistent northwesterly winds (R. Thomson, pers. comm.). This may explain the elevated biomass during the July 1998 cruise. Both regions showed high variability but on average, variability was higher in the shelf region than the beyond shelf region.

A3) ALONG-SHORE GRADIENT

There was no consistent alongshore trend for the shelf or beyond shelf region in 1997 or 1998 (Figure 1.10). The transect where the highest biomass was measured was different during each cruise. In fact, during one cruise the maximum may be at one particular transect whereas for the next cruise the minimum may be at the same transect. For example, a north-south trend in the shelf region was observed during April 1997 (Figure 1.10A). Biomass tended to increase north of La Pérouse Bank but then for July 1997, biomass decreased from the southern transect to the northern transect.

For October 1997, the difference in biomass between Estevan Point and Barkley Canyon in the shelf region was signifiantly different (Tukey test, $p<0.05$). The result of an ANOVA test indicates highly significant differences between the transects during July 1998 ($p<0.01$). A Tukey test showed a significant difference between Estevan Point and both Barkley Canyon and Brooks Peninsula ($p<0.05$), but no significant difference between Barkley Canyon and Brook Peninsula ($p>0.05$).

A4) SUMMARY OF CHLORPHYLL CONCENTRATIONS

In summary, chlorophyll was significantly higher in 1998 compared to 1997. A cross-shelf gradient was observed where chlorophyll was significantly higher in the shelf regions than in the beyond the shelf regions. There was no north-south gradient in the shelf or the beyond shelf region for 1997 or 1998. Chlorophyll was consistently higher in July relative to April/May or October for both study regions. Maximum biomass measured for the 2 study years was <20.0

mg chl m^{-3}, or 428 mg chl m^{-2}. During this study period, the highest biomass was measured in July 1998, which was the only cruise during the two year study that had conditions favorable for upwelling.

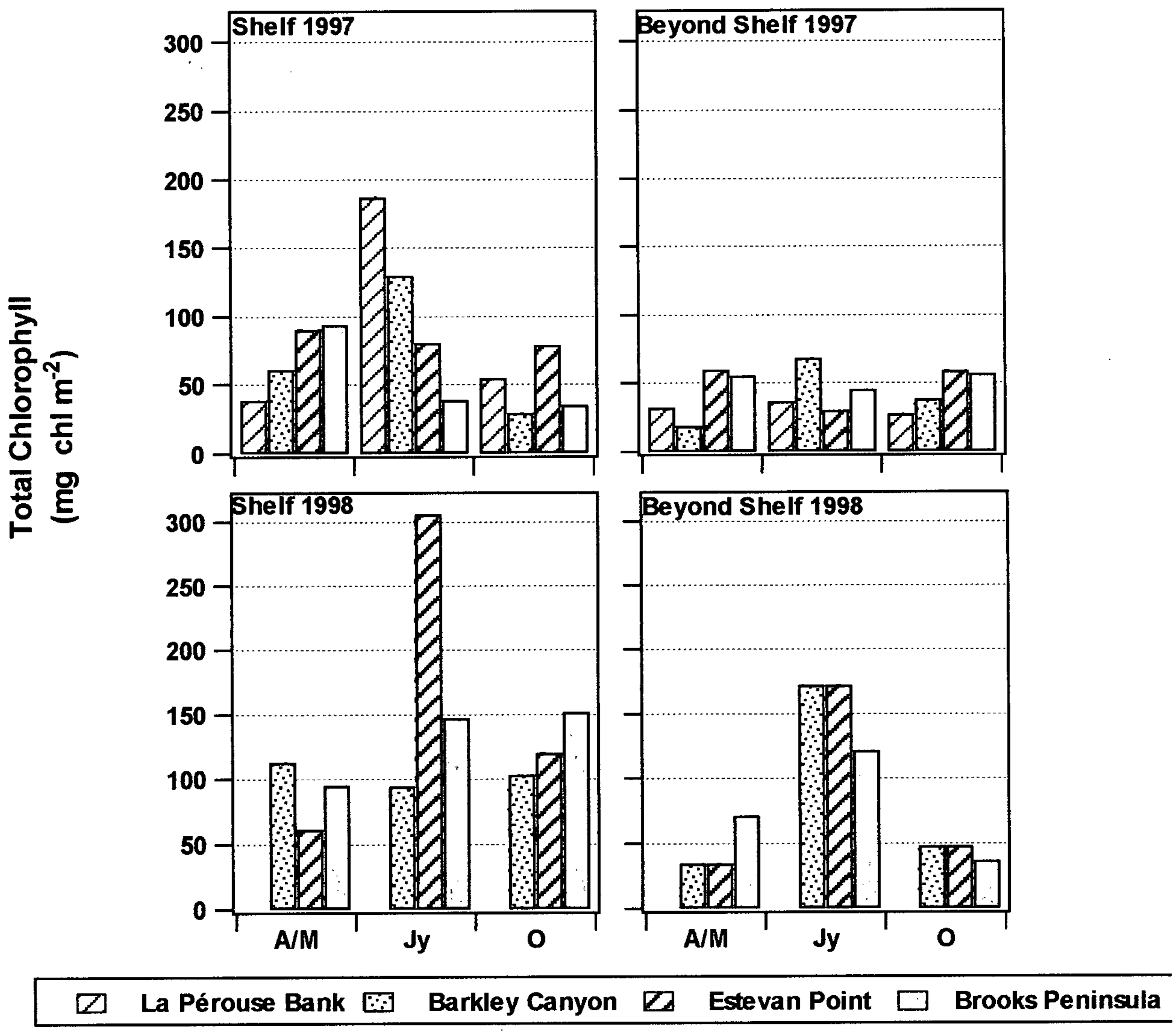

Figure 1.10 Total chlorophyll of the shelf and the beyond shelf region of the La Pérouse Bank, Barkley Canyon, Estevan Point and Brooks Peninsula transect off the west coast of Vancouver Island in 1997 and 1998. A=April, M=May, J=July and O=October.

Table 1.6 Mean integrated chlorophyll ± 1 S.D. (mg chl m^{-2}) and coefficient of variation (CV; %) for 1997 and 1998 for shelf and beyond shelf stations along La Pérouse Bank, Barkley Canyon, Estevan Point and Brooks Peninsula off the west coast of Vancouver Island. Mean for each cruise and each year are given.

Date	**Region**	**Chlorophyll**		**CV**		**n**	
		Shelf	**Beyond**	**Shelf**	**Beyond**	**Shelf**	**Beyond**
April 1997	La Pérouse Bank	38.8 ±0.80	32.2 ±12.3	2.2	38	2	3
	Barkley Canyon	61.0 ±13.5	18.9 ±11.3	22	60	4	3
	Estevan Point	90.4 ±61.3	59.6 ±22.6	67	38	4	3
	Brooks Peninsula	93.9 ±63.6	55.2 ±20.3	68	37	2	2
	WCVI Mean	71.0 ±34.8	41.4 ±16.6	38	43	Σ12	Σ11
July 1997	La Pérouse Bank	187 ±122	36.6 ±15.8	65	43	5	2
	Barkley Canyon	130 ±60.5	68.4 ±22.9	46	33	3	4
	Estevan Point	80.4 ±25.7	30.1	32	-	3	1
	Brooks Peninsula	38.8 ±7.3	45.2 ±38.2	19	85	3	3
	WCVI Mean	109 ±53.9	45.1 ±28.2	41	40	Σ14	Σ10
Oct. 1997	La Pérouse Bank	54.4 ±24.2	27.7	45	-	5	1
	Barkley Canyon	29.6 ±6.0	38.3±6.80	20	18	3	3
	Estevan Point	78.8 ±13.3	58.8±47.1	17	80	4	3
	Brooks Peninsula	35.1 ±8.3	56.6±36.8	24	65	3	4
	WCVI Mean	49.5 ±13.0	45.4±22.7	26	54	Σ15	Σ11
1997	WCVI Mean	76.5 ±45.8	43.9 ±15.5	60	35	41	32
May 1998	La Pérouse Bank	-	-	-	-	-	-
	Barkley Canyon	113 ±91.5	29.8 ±11.0	81	37	6	4
	Estevan Point	61.5 ±22.3	34.8 ±12.1	36	35	4	3
	Brooks Peninsula	95.4	71.2 ±16.0	-	23	1	6
	WCVI Mean	89.8 ±37.9	45.3 ±13.0	39	31	Σ11	Σ13
July 1998	La Pérouse Bank	-	-	-	-	-	-
	Barkley Canyon	94.1 ±28.4	54.6 ±11.1	30	20	4	4
	Estevan Point	306 ±88.0	172 ±103.8	29	60	3	3
	Brooks Peninsula	147 ±66.6	121 ±49.0	45	40	3	4
	WCVI Mean	182 ±61.0	116 ±54.6	36	40	Σ10	Σ9
Oct. 1998	La Pérouse Bank	-	-	-	-	-	-
	Barkley Canyon	103 ±53.8	37.2 ±14.7	55	40	4	4
	Estevan Point	120 ±64.2	48.1 ±10.4	54	22	3	2
	Brooks Peninsula	152 ±62.5	37.0 ±6.80	41	18	3	4
	WCVI Mean	125.0 ±60.2	40.8 ±10.6	50	27	Σ11	Σ10
1998 Mean	WCVI Mean	132 ±70.7	67.4 ±48.3	53	39	33	32
2 yr Mean	WCVI	101 ±62.9	54 ±34.7	63	64	74	64

B) PHYTOPLANKTON ASSEMBLAGES

Phytoplankton taxonomic analysis was completed at the same stations that primary productivity were measured. At a single station in each of the shelf and beyond shelf regions was two samples collected, one at each of the 55% and 1% surface light level. A list of all species found during 1997 and 1998 are listed in Tables 1.7 and 1.8. The category 'diatoms' includes all species listed in Table 1.7 and photosynthetic flagellates refers to all species listed in Table 1.8. Abundances of diatoms, nanoflagellates, and dinoflagellates for 1997 and 1998 are included in Table 1.9 and 1.20.

B1) TOTAL ABUNDANCE AND BIOMASS

On average, the total cell abundance was higher in 1997 (6.1 $\times10^6$ cells L^{-1}) compared to 1998 (4.7 $\times10^6$ cells L^{-1}), in contrast to higher biomass in 1998 compared to 1997 (Figure 1.11). The decrease in cell abundance in 1998 was due to fewer nanoflagellates and the increase in biomass in 1998 was due to increased presence of diatoms.

Total cell abundance and total biomass were consistently higher in shelf regions than beyond shelf regions (Figure 1.11). For 1998, the difference in cell abundance and biomass between the two regions was significantly different ($p<0.05$).

A seasonal trend was evident for total cell abundance for 1997 and 1998 (Figure 1.12). Generally total abundance peaked in July. For total biomass, a consistent seasonal trend was not observed for 1997 and 1998. In 1997, biomass peaked in July while in 1998 biomass peaked in May.

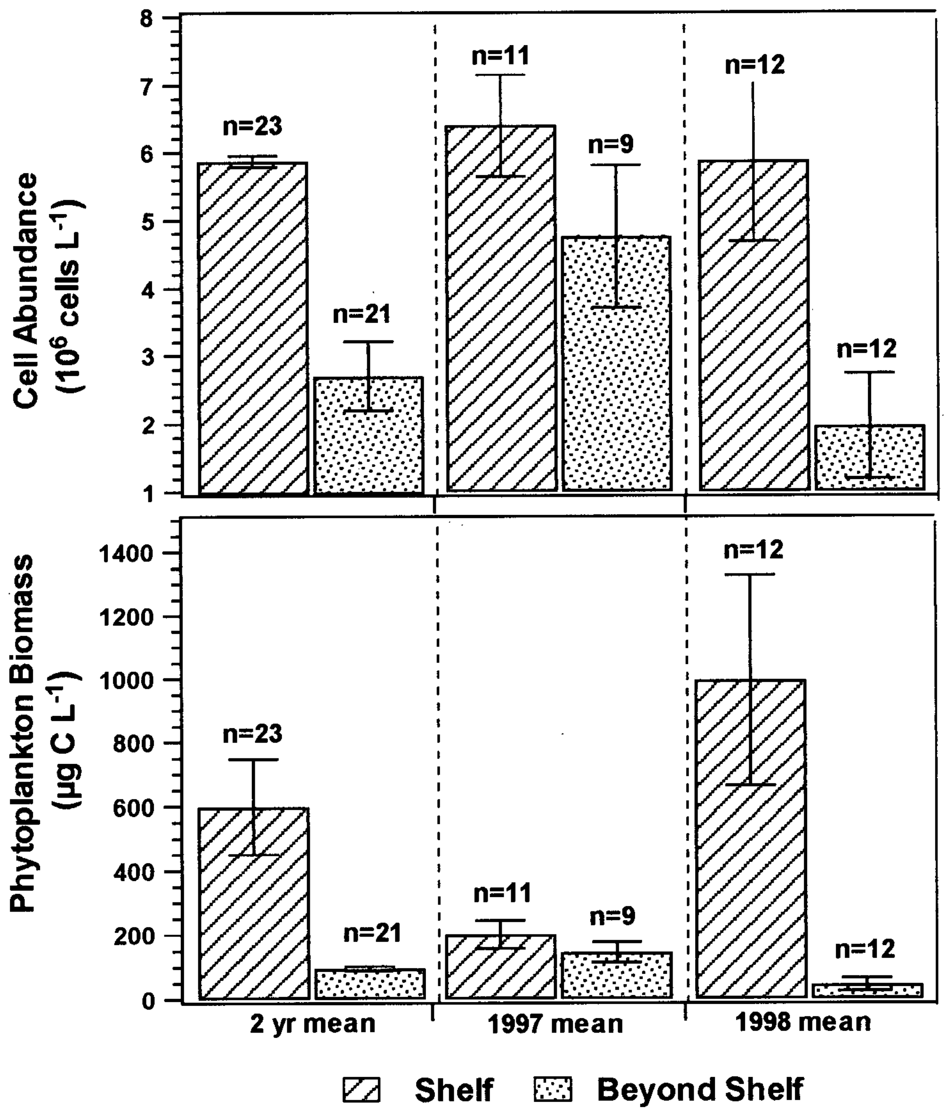

Figure 1.11 Interannual mean and annual means of total cell abundance and phytoplankton biomass ± 1 S.D. for the shelf and the beyond shelf regions off the west coast of Vancouver Island in 1997 and 1998. Shelf values are the mean of all shelf stations sampled and beyond shelf values are the mean of all beyond shelf stations.

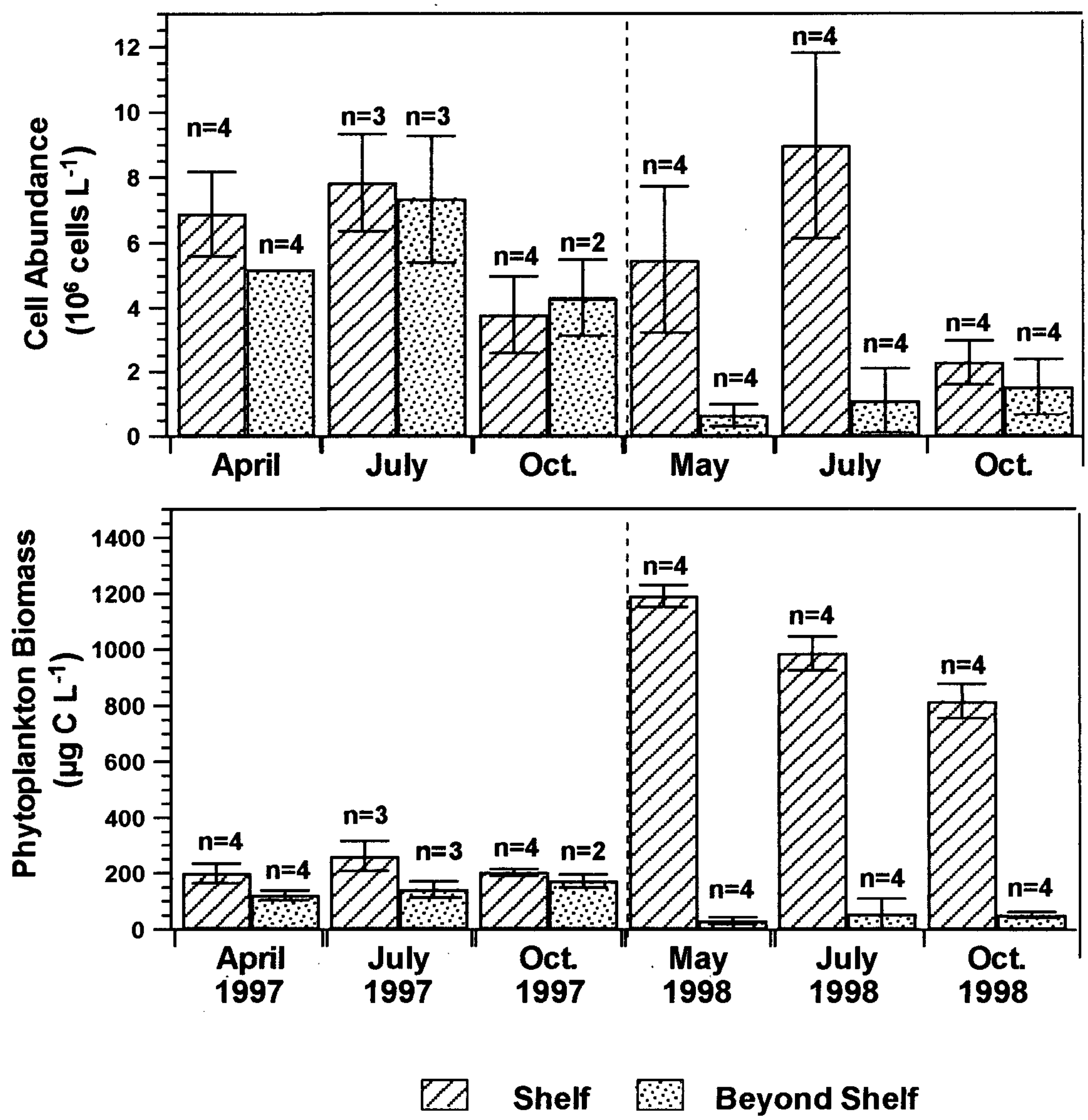

Figure 1.12 Seasonal variability of total cell abundance and phytoplankton biomass ± 1 S.D. for the shelf and the beyond shelf regions off the west coast of Vancouver Island in 1997 and 1998. Shelf means are the average of all shelf stations sampled during each cruise and beyond shelf values are the mean of all beyond shelf stations during each cruise.

B2) COMMUNITY STRUCTURE

The phytoplankton community of shelf and beyond shelf regions were generally numerically dominated by nanoflagellates during the study period (Figure 1.13A). Generally nanoplankton were mainly composed of unidentified miscellaneous flagellates, but peaks of

Mantoniella squamata, Micromonas pusilla and coccolithophores were observed. *Chrysochromulina* spp. and *Crypotomonas* spp. were observed but they never dominated the nanoflagellate assemblage.

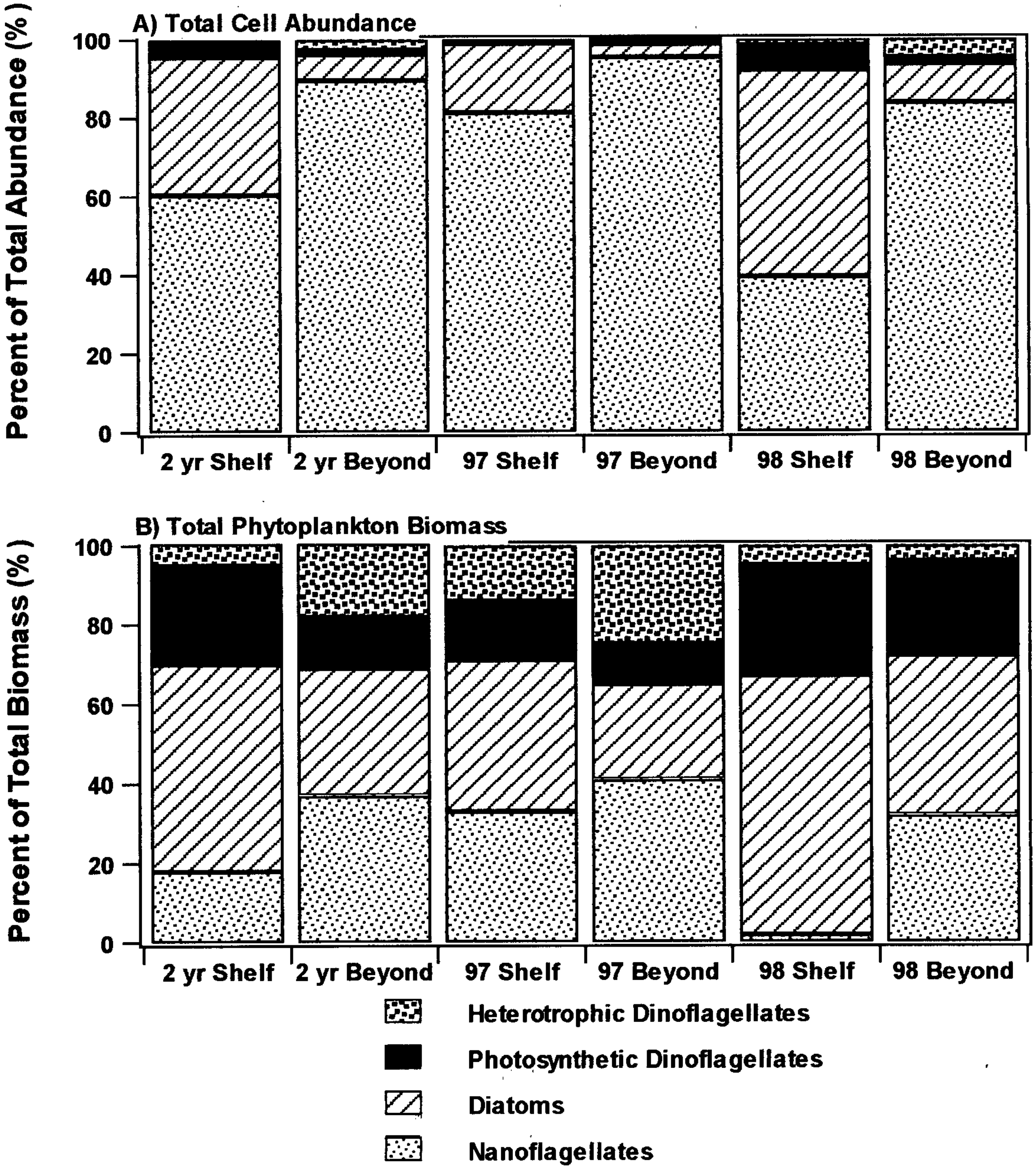

Figure 1.13 Contribution of each phytoplankton group to: A) total cell abundance, and B) total phytoplankton biomass (µg L^{-1}) of the shelf and beyond shelf region off the west coast of Vancouver Island for 1997, 1998 and the 2 yr mean.

Despite their numerical dominance, they contributed substantially less to total biomass due to their small size (Figure 1.13B). For 1998, a change in community structure was observed. The contribution of diatoms to total abundance and biomass increased significantly in 1998 from 1997 ($p<0.05$) (Figure 1.13). The increase was particularly notable for May and July 1998 (Figure 1.14). The diatom assemblage was frequently composed of *Pseudo-nitzschia* spp *Chaetoceros* spp., *Skeletonema costatum, Leptocylindrus danicus, Detonula pumila, Asterionella glacialis.* The contribution of diatoms to abundance and biomass was less in the beyond shelf region. The relative contribution of diatom to total biomass for the October 1998 cruise was low, which was expected since the cruise occurred after the fall transition had occurred.

Three obvious features of the relative contribution of the different phytoplankton groups are: 1) diatoms tend to account for a high proportion of total biomass in April/May and July, particularly for the shelf region, 2) the contribution by photosynthetic dinoflagellates, dominated by *Gymnodinium* spp. tends to increase in the fall (Figure 1.14) and 3) heterotrophic dinoflagellates dominated by *Gyrodinium* spp., contributed the least to total cell abundance during the study period.

The variability in cell abundance was higher for diatoms than for nanoflagellate during both study years. The variability of autotrophic and heterotrophic dinoflagellates abundance was high. The variability in biomass was higher in diatoms than nanoflagellates during 1997, while for 1998 the variability was higher for nanoflagellates.

Mesodinium rubrum is a ciliate that contains chloroplasts (Taylor *et al.*, 1971) and commonly blooms in upwelling regions. Generally the abundance was higher in the shelf region compared to the beyond shelf region; 4% of the total biomass was accounted for by *Mesodinium rubrum* in the shelf region compared to 1% in the beyond shelf region. Abundance and biomass were higher in 1997 relative to 1998. On average, they accounted for 5% of the biomass for 1997 and 1% for 1998. Generally, the contribution of *Mesodinium rubrum* to abundance and biomass was low during the study period.

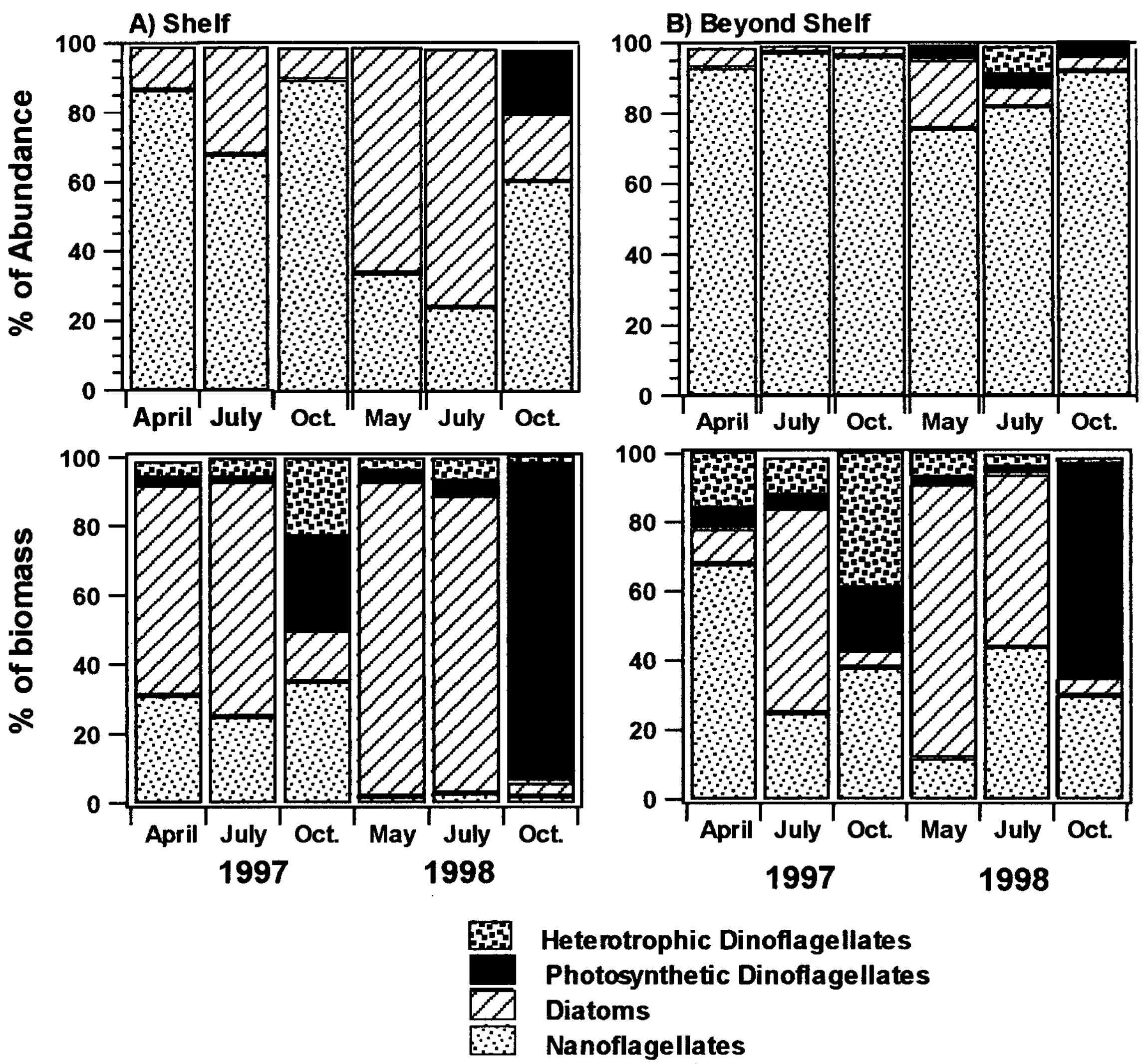

Figure 1.14 Contribution of each phytoplankton group to total cell abundance and biomass of: A) shelf and B) beyond shelf regions off the west coast of Vancouver Island in 1997 and 1998. Groups contributing <2% were not included.

B3) SUMMARY OF PHYTOPLANKTON ASSEMBLAGES

In summary, phytoplankton biomass was higher in 1998 due to increased abundance of diatoms. Diatom blooms in 1998 were mainly composed of *Chaetoceros debilis* and *Leptocylindrus danicus*. The phytoplankton biomass was higher in shelf regions than beyond shelf regions for all cruises and all transects. The biomass of diatom species dominated the shelf regions during the spring and summer cruises and autotrophic flagellates dominated the biomass during October. The contribution of autotrophic and heterotrophic dinoflagellates was generally low, but particularly during the fall, the relative contribution to abundance and biomass increased. A change in community structure was observed in 1998, with blooms of diatoms that were not observed during the 1997 season.

Table 1.7 List of diatoms identified from samples collected off the west coast of Vancouver Island from May 1997 to October 1998. X in 1997/1998 column signifies the diatom was observed in either April/May, July or October.

Bacillariophyceae	Species	1997	1998
Centric Diatoms	*Chaetoceros* spp.*	X	X
	Chaetoceros compressus	X	X
	Chaetoceros convolutus	X	X
	Chaetoceros debilis	X	X
	Chaetoceros eibenii		X
	Chaetoceros radicans	X	X
	Chaetoceros socialis		X
	Detonula pumila	X	
	Leptocylindrus danicus	X	X
	Leptocylindrus minimus	X	X
	Proboscia alata (formally *Rhizosolenia alata*)	X	X
	Dactyliosolen fragilissimus (formally *Rhizosolenia fragilissima*)	X	X
	Rhizosolenia setigera		X
	Guinardia striata (formally *Rhizosolenia stolterfothii*)	X	X
Pennate Diatoms	*Asterionella glacialis*		X
	Cylindrotheca closterium	X	X
	Fragilaria spp.	X	
	Navicula spp.	X	X
	Nitzschia spp.	X	X
	Pseudo-nitzschia spp.*	X	X
	*Pseudo-nitzschia delicatissima**	X	X
	Pseudo-nitzschia pungens		X
	Thalassionema nitzschoides	X	X
	Thalassiosira aestivalis	X	X
	Thalassiosira spp. *	X	X
	Thalassiosira rotula		X
	Thalassiosira nordenskioeldii	X	X
	*Skeletonema costatum**	X	X
	Synedra spp.	X	

* Most abundant species

Table 1.8 List of autotrophic flagellates identified from samples collected off the west coast of Vancouver Island from May 1997 to October 1998. X signifies species was observed in either April/May, July or October.

	Species	**1997**	**1998**
Dinophyceae	*Alexandrium tamarense*		X
	Ceratium kofoidii		X
	Gymnodinium spp.	X	X
	Gyrodinium fusiforme		X
	Gyrodinium spp.	X	X
	Katodinium rotundatum	X	X
	Prorocentrum balticum		X
	Prorocentrum gracile	X	X
	Protoperidinium rhomboidalis	X	
	Protoperidinium spp.		X
Prymnesiophyceae	*Chrysochromulina* spp.*	X	X
	Coccolithophores	X	X
Chrysophyceae	*Dictyocha speculum*	X	
Prasinophysceae	*Micromonas pusilla*	X	X
	Mantoniella squamata	X	X
Cryptophyceae	*Leucocryptos marina*		X
	Cryptomonad spp.	X	
Ciliate	*Mesodinium rubrum*	X	X

* Most abundant species

Table 1.9. Abundance of diatoms, nanoflagellates, autotrophic and heterotrophic dinoflagellates during April, July and October 1997 off the west coast of Vancouver Island. LP=La Pérouse Bank BC=Barkley Canyon, EP=Estevan Point, BP=Brooks Peninsula. See Figure 1.1 for location of transects. (–) indicates no sample taken, * indicates the most abundant group.

Region	**Diatoms** 10^5 Cells l^{-1}	**Nanoflagellates** 10^5 Cells l^{-1}	**Autotrophic Dinoflagellates** 10^5 Cells l^{-1}	**Heterotrophic Dinoflagellates** 10^5 Cells l^{-1}
April 1997				
LP-Shelf	0.96	46.1 *	0.16	0.08
LP-Beyond Shelf	0.23	12.2 *	0.08	0.09
BC-Shelf	1.52	96.6 *	0.76	0.41
BC-Beyond Shelf	0.02	85.4 *	0.02	0.14
EP-Shelf	14.2	33.3 *	0.25	0.16
EP-Beyond Shelf	2.67	75.4 *	0.49	0.24
BP-Shelf	13.4	67.1 *	0.17	0.43
BP-Beyond Shelf	5.13	24.6 *	0.78	0.15
Mean-Shelf	7.5	60.8 *	0.34	0.27
Mean-beyond	2.0	49.4 *	0.34	0.16
July 1997				
LP-Shelf	52.8 *	37.2	0.23	0.19
LP-Beyond Shelf	0.01	4.58 *	0.02	0.02
BC-Shelf	15.7	86.0 *	0.22	0.16
BC-Beyond Shelf	-	-	-	-
EP-Shelf	8.36	33.2 *	0.52	0.51
EP-Beyond Shelf	0.38	81.4 *	0.10	0.13
BP-Shelf	-	-	-	-
BP-Beyond Shelf	2.38	40.4 *	0.34	0.28
Mean-Shelf	25.6	52.2 *	0.32	0.29
Mean-beyond	0.92	42.1 *	0.15	0.14
October 1997				
LP-Shelf	1.80	28.4 *	0.20	0.19
LP-Beyond Shelf	-	-	-	-
BC-Shelf	0.72	7.67 *	0.05	0.12
BC-Beyond Shelf	0.31	16.4 *	0.06	0.11
EP-Shelf	10.2	35.8 *	0.49	0.34
EP-Beyond Shelf	-	-	-	-
BP-Shelf	0.32	64.3 *	0.32	0.34
BP-Beyond Shelf	1.68	47.8 *	0.21	0.77
Mean-Shelf	3.26	34.1 *	0.26	0.24
Mean-Beyond	1.0	32.1 *	0.13	0.43
1997 Mean-Shelf	12.1	49.0 *	0.31	0.27
1997 Mean-Beyond	1.3	41.0 *	0.20	0.25

Table 1.10 Abundance of diatoms, nanoflagellates, autotrophic dinoflagellates and heterotrophic dinoflagellates at 55% surface light depth during May, July and October 1998 off the west coast of Vancouver Island. LP=La Pérouse Bank BC=Barkley Canyon, EP=Estevan Point, BP=Brooks Peninsula. See Figure 1.1 for location of transects. * = most abundant group.

Region	**Diatoms** 10^5 Cells l^{-1}	**Nanoflagellates** 10^5 Cells l^{-1}	**Autotrophic Dinoflagellates** 10^5 Cells l^{-1}	**Heterotrophic Dinoflagellates** 10^5 Cells l^{-1}
May 1998				
LP-Shelf	46.8 *	3.32	0.52	0.44
LP-Beyond Shelf	0.01	43.6 *	0.13	0.06
BC-Shelf	6.99	8.34 *	0.04	0.03
BC-Beyond Shelf	0.003	6.21*	0.01	0.02
EP-Shelf	1.20	30.3 *	0.07	0.64
EP-Beyond Shelf	74.4 *	34.7	1.62	1.69
BP-Shelf	15.2	15.6 *	0.02	0.06
BP-Beyond Shelf	8.55	11.5 *	0.02	0.12
Cruise Mean-shelf	17.5 *	11.7	0.16	0.29
Cruise Mean-beyond	20.7 *	10.0	0.41	0.47
July 1998				
LP-Shelf	8.19 *	3.32	0.04	0.10
LP-Beyond Shelf	0.02	2.81 *	0.01	0.18
BC-Shelf	102 *	43.9	0.05	0.58
BC-Beyond Shelf	0.01	0.21	0.02	0.04
EP-Shelf	74.4	26.9 *	1.62	1.68
EP-Beyond Shelf	0.01	8.29*	0.02	0.04
BP-Shelf	81.2	12.5	0.91	1.08
BP-Beyond Shelf	7.44	33.0 *	0.15	0.23
Cruise mean-shelf	66.4 *	21.7	0.78	0.86
Cruise mean-beyond	1.86	9.06 *	0.05	0.12
October 1998				
LP-Shelf	0.55	4.55 *	1.45	0.34
LP-Beyond Shelf	0.39	37.7 *	0.09	0.28
BC-Shelf	19.0 *	15.0	0.12	0.35
BC-Beyond Shelf	0.09	1.18 *	0.01	0.05
EP-Shelf	1.91	25.4 *	5.87	0.57
EP-Beyond Shelf	0.18	17.0	0.48	0.17
BP-Shelf	1.18	9.15 *	5.46	0.38
BP-Beyond Shelf	0.34	3.54 *	0.06	0.05
Cruise mean-shelf	5.66	13.5 *	3.22	0.41
Cruise mean-beyond	0.24	14.9 *	0.16	0.13
1998 mean-shelf	29.9 *	15.6	1.40	0.52
1998 mean-beyond	7.6	11.3 *	0.20	0.24

Table 1.11 Summary of characteristics of shelf and beyond shelf regions off the west coast of Vancouver Island. Values are for 1997 and 1998. Units for parameters below are: ML, meters; temperature, °C, nitrate, μM; chlorophyll, mg chl m^{-2}; CV, %)

		Shelf	**Beyond**
Mixed layer depth		11.8	23.2
Mixed layer temperature		11.9	12.8
Mixed layer salinity		31.1	31.5
NO_3	1997	7.5	3.1
	1998	4.6	1.6
	2 yr mean	6.1	2.4
HPO4	1997	0.7	0.4
	1998	0.9	0.4
	2 yr mean	0.8	0.4
$Si(OH)_4$	1997	16.9	9.4
	1998	10.3	4.0
	2 yr mean	13.8	6.6
Total Chl	surface range	0.21-19.7	0.12-12.7
	1997	76.5	43.9
	1998	132	67.4
	2 yr mean	104	55.7
	CV	63	64
%	1997	33	41
	1998	2	32
	2 yr mean	18	37
	CV	75	14
% Diatoms	1997	38	24
	1998	65	40
	2 yr mean	52	32
	CV	8	7

DISCUSSION

West coast of Vancouver Island

Variability was very high off the west coast of Vancouver Island, and often the standard deviation was similar to the mean. This makes it difficult of determine the significance of differences between regions and between years and therefore this thesis also contains comments on trends or patterns. Landry *et al.* (1989) have also shown that means of temperatures, salinities, winds, currents, nitrate and chlorophyll are only known within large limits of uncertainty. They also pointed out that the variability of these parameters was an important ecological parameter in its own right.

Nutrients and biomass off the west coast of Vancouver Island were generally high but on several occasions and at several locations nutrient concentrations were at or near detection limits. Surface nitrate up to 14-15 μM was observed but on average nitrate, phosphate and silicic acid concentrations for the west coast of Vancouver Island were 4.1, 0.7 and 12 μM respectively for the study period. A maximum of 306 mg chl m^{-2} was observed and on average chlorophyll was 77.2 mg chl m^{-2} off the west coast of Vancouver Island.

Generally, the mixed layer depth was deeper and more saline in 1998 for both the shelf and the beyond shelf regions. This is reasonable considering more intense upwelling was observed in 1998, which would inject high salinity water into the surface layers. The mixed layer temperatures were on average similar for both years. On average, biomass was lower in 1997 than in 1998 while on average nutrients were higher in 1997 than in 1998. It is likely that the high phytoplankton biomass observed in 1998 was responsible for drawing down nutrient concentrations. This scenario is even more plausible considering the high intensity of upwelling and high flux of nutrients to the surface. Upwelling as a nutrient source should be higher in 1998 than in 1997. Depletion of surface NO_3^- in 1998 suggests primary productivity may have been nutrient limited during periods. The seasonality of nutrient concentrations varied between years. In 1997, nitrate and silicic acid were highest in April and lowest in October, whereas in 1998 concentrations were the lowest in April and the highest in October. A distinct change in phytoplankton community structure occurred in 1998. During the 1997 cruises, the relative contribution of diatoms was low, but during the 1998 season the diatoms returned and contributed significantly to total biomass. This suggests that during periods of intense upwelling the fast growing diatoms outcompete other species.

The various physical, chemical and biological parameters off the west coast of Vancouver Island varied considerably in the cross-shelf direction (E/W). For a summary of shelf and beyond shelf parameters see Table 1.11. The mean mixed layer depth was deeper, warmer and more saline beyond the shelf than in the shelf region. Nutrient concentrations and biomass were higher in the shelf region than in the beyond shelf region. The phytoplankton community structure of shelf and beyond shelf regions was distinct from each another. The diatoms had a greater contribution to total biomass in the shelf region than in the beyond shelf region. Generally the diatom assemblage was composed of *Pseudonitzschia spp.*, *Chaetoceros debilis*, *Skeletonema costatum*, *Asterionella glacialis*, *Dactyliosolen fragillissimus*, but was dominated by *Chaetoceros debilis* and *Leptocylindrus danicus*. The phytoplankton assemblage in the beyond shelf regions were composed of *Chrysochromulina* spp., and cryptomonads, but it was generally dominated by miscellaneous unidentified flagellates.

In addition to cross shelf differences, physical, chemical and biological parameters varied considerably in the along shore directions (N/S). There was no consistent trend along the length of Vancouver Island for the shelf region or the beyond shelf region. The high variability in the cross-shore direction and along shore direction suggests environmental conditions vary considerably off the west coast of Vancouver Island.

The distribution of nutrients and phytoplankton biomass off the west coast of Vancouver Island showed considerable variation in time. Seasonality of biomass was similar in 1997 and 1998. The seasonal peak in biomass and diatom abundance for each year was seen in July for 1997 and 1998, while the highest biomass during the study period were measured in July 1998. During May and July 1998 the relative contribution of the diatoms reached 91 and 86% of total cell biomass. It is interesting to note that during the entire study, the July cruise was the only cruise that occurred during upwelling favorable conditions.

Comparison with previous studies off the west coast of Vancouver Island

A distinct cross-shelf gradient was observed during this study. This finding confirms previous results (Mackas, 1992) which showed a general cross-shelf gradient in physical, chemical and biological properties. The shelf was characterized by cooler temperature, lower salinity, higher dissolved nutrients, and higher biomass than the beyond shelf region. The lower salinity reflects the strong regional influence of the Vancouver Island Coastal Current (Freeland *et al.* 1984; Thomson *et al.* 1989). The results of this study are consistent with those reported by Mackas (1992). Denman *et al.* (1989) found that continental shelf waters are generally retained along the continental margin which may in part, explain the distinct characteristics of shelf regions and beyond shelf regions observed during this study.

Nitrate concentrations reported by Mackas (1992) were similar to those found in this study. One different feature observed during this study was for May and July 1998 nitrate concentrations were frequently at or near detection limits, whereas Mackas (1992) found surface nitrate was very rarely depleted to undetectable levels. This difference may be explained by low upwelling during the strong El Niño. Chlorophyll concentrations reported by this study were similar to those reported by Mackas (1992), both in mean concentration and seasonality.

Comparison of the taxonomy data with other studies is limited since there have been no detailed taxonomic studies off the west coast of Vancouver Island, although Taylor and Haigh (1996) have examined the microplankton community structure of Barkley Sound. They found that the summer community was dominated by diatoms, typical of coastal waters. These observations are similar to results presented in this thesis and similar to results reported by Mackas *et al.*1980; Perry *et al.* 1999.

Taylor and Haigh (1996) reported over 14 harmful phytoplankton species in Barkley Sound. This study did not examine the distribution of harmful algal species specifically, but *Alexandrium tamarense, Chaetoceros convolutus, and Pseudo-nitzschia delicatissima, Gymnodinium auratum, Pseudo-nitzschia pungens* were all observed during the study period. In addition, Taylor and Haigh (1996) suggested that strong dinoflagellate blooms are more common in the fall. This study has shown that the contribution of dinoflagellates was the highest in the fall of 1998.

Comparison with other upwelling regions

The nutrient and biomass distribution off the west coast of Vancouver Island are similar to the coastal upwelling areas off Washington and Oregon (Landry *et al.* 1989) and off California (Wilkerson *et al.* 2000). In general, nutrient and biomass concentrations were high (>5 μM) and a sharp cross-shelf distribution of nutrients and biomass were observed. Small and Menzies (1981) have shown that the highest biomass developed within 20 km of the shore. This is consistent with the results of this study. Landry *et al.* (1989) reported that concentrations of nitrate are replenished in the summer after the seasonal low in April caused by the spring bloom. During 1998, the year of intensive upwelling, this study has shown that nitrate was replenished after low concentrations found in May.

Low or undetectable levels of nutrients were found during 1998 which differs from previous studies (e.g. Mackas, 1992) that found detection limits were rarely observed off the west coast of Vancouver Island. Lower nutrient concentrations during the El Niño year compared to non-El Niño years are reported by Barber and Chavez, 1983; Barber and Chavez, 1986; and Wilkerson *et al.* 1987). It is possible that the strong El Niño during 1997/98 may have reduced the winter and summer nutrient supply to the shelf region allowing for rapid depletion of a smaller nitrate pool resulting in undetectable nitrate concentrations. Off the coast of Washington and Oregon depletion of nitrate was common, particularly after the spring bloom in April (Landry *et al.* 1989).

The higher contribution of diatoms to the abundance and biomass during May and July 1998 is consistent with results found by Chavez (1996). Generally during upwelling conditions, he found high diatom abundance that dominated the phytoplankton biomass.

SUMMARY OF CHAPTER ONE

In general, the physical, chemical and biological parameters showed interannual variability. Differences between the two sampling years include: shallower mixed layer in 1997; lower salinity and density in 1997; higher nitrate and silicic acid concentration in 1997; lower chlorophyll in 1997; higher phytoplankton abundance in 1997, lower phytoplankton biomass and lower diatom abundance and biomass in 1997. There was no difference between mixed layer temperature between 1997 and 1998. During 1997 nanoplankton dominated the community structure while in 1998, diatoms dominated. This suggests that the 1997 oceanic environment was not favorable for large cells, and was perhaps due to El Niño conditions.

CHAPTER 2

SIZE-FRACTIONATED BIOMASS AND PRIMARY PRODUCTIVITY OFF THE WEST COAST OF VANCOUVER ISLAND

Introduction

There is increasing evidence of synchronous changes in the climate and the ocean environment in the Pacific Ocean (Beamish *et al.*, 1999). Large fluctuations of Pacific salmon stocks, shifts in mesozooplankton abundance (Brodeur and Ware, 1992; Sugimoto and Tadokora, 1997), chlorophyll (Venrick *et al.* 1987) and nutrient distribution (Whitney *et al.* 1998) in this century are linked to changed in the climate and to physical changes in the ocean. It is reasonable to assume that if trends in climate match trends in fish, zooplankton and chlorophyll, then primary productivity may be impacted as well. A persistent trend in climate/ocean conditions is called a regime (Beamish *et al.* 1999b). It is important to recognize that physical and biological mechanisms may change when regimes shift. The regime shifts are important in fisheries management because the natural shifts may be large and sudden, requiring that these natural impacts be incorporated into management plans. In order to assess the possible climatic impact on ecosystem productivity, long term data bases are necessary because it is difficult to assess decadal trends when the database is less than 20 years. Often observations fail to examine critically important environmental disturbances such as ENSO (El Niño-Southern Oscillation) events.

The measurement of size-fractionated biomass and primary productivity is important to understand the response of the phytoplankton assemblage to fluctuating environmental conditions. A better understanding of the community response will further aid our understanding of the functioning of the pelagic foodweb. This is the first study of size-fractionated biomass and primary productivity off the west coast of Vancouver Island. In addition, this study examines a large fluctuation in the ocean regime and its impact on phytoplankton communities during 1997 (strong El Niño) and 1998 (strong La Niña).

The goals of this study were to:

(1) investigate the size structure of the phytoplankton biomass and primary productivity along the west coast of Vancouver Island,

(2) determine if increases in biomass and primary productivity are due to the larger size fraction, and

(3) determine if the size structure or total primary productivity was impacted during the strong ENSO event of 1997 and 1998.

MATERIALS AND METHODS

Total and size-fractionated phytoplankton biomass and primary productivity in the euphotic zone were investigated on 4 transects over the continental margin off the west coast of Vancouver Island. At each of the four transects, sampling stations were chosen in order to have one station on and one station off the continental margin, making a total of 8 stations (Figure 2.1). The transects were off La Pérouse Bank, Barkley Canyon, Estevan Point and Brooks Peninsula. Size-fractionated chlorophyll and size-fractionated primary productivity were measured on water samples collected at 6 depths corresponding to 100, 55, 30, 10, 3.5, and 1% of the surface light intensity (I_o).

Chemical and biological measurements

Water samples for nitrate + nitrite ($NO_3^- + NO_2^-$), soluble reactive phosphate (HPO_4^{2-}), and silicic acid ($Si(OH)_4$) were collected at 6 depths in the euphotic zone and processed as outlined and discussed in Chapter 1.

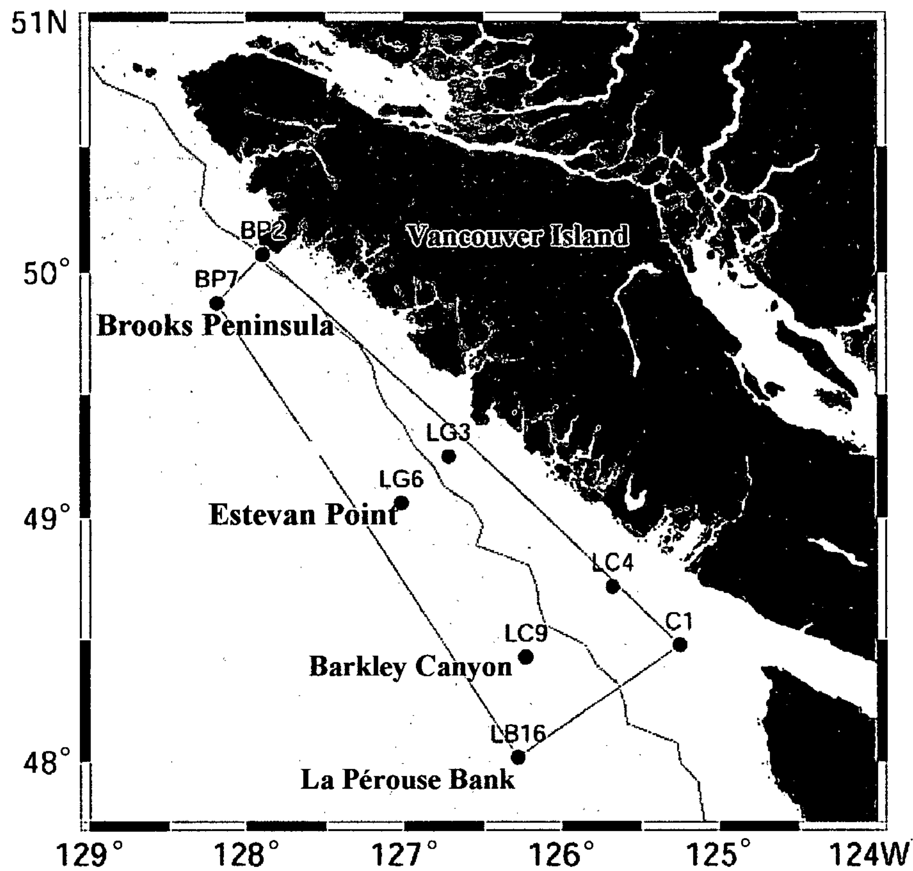

Figure 2.0 Location of study area off the west coast of Vancouver Island. Dashed line is the 200 m contour. The box delineates the study area. C1, LC4, LG3, BP2 are shelf stations and LB16, LC9, LG9, BP7 are beyond shelf stations. C1 and LB16 =La Pérouse Bank transect, LC4 and LC9 = Barkley Canyon transect, LG3 and LG6 = Estevan Point transect and BP2 and BP7 = Brooks Peninsula transect.

Duplicate samples (0.5 L) for size-fractionated chlorophyll concentration (corrected for phaeopigments) were collected at 6 water depths in the euphotic zone and processed using parallel filtration. Water samples were filtered through 25 mm 0.7 μm glass-fiber filters (Whatman GF/F or AMD GF75) for total chlorophyll and through a 47 mm Nuclepore® 5 μm polycarbonate filter for the >5 μm fraction. Samples were extracted for chlorophyll and calculations were made according to the methods outlined in Chapter 1. The <5 μm size fraction was calculated as the difference between total chlorophyll and the >5 μm chlorophyll sample. To evaluate the contribution of the >5 μm sized cells to the phytoplankton biomass, the >5 μm size fraction values were calculated as percentages of the total phytoplankton biomass.

Primary productivity

During each cruise, an attempt was made to occupy process stations before dawn but sampling logistics and weather conditions sometimes prohibited this plan. Water was sampled using 10 L acid-cleaned PVC Niskin bottles fitted with silicone O-rings and Teflon-covered closure springs mounted on an instrumented rosette equipped with a Biospherical Instruments 4 π light sensor. The PAR sensor trace was examined on the downcast to identify the six water depths corresponding to 100, 55, 30, 10, 3, 1% of incident surface photosynthetic photon flux density (PPFD). Samples were transferred directly from the Niskin bottle to 70 ml acid-cleaned polycarbonate (Nalgene®) incubation bottles without using a siphon tube to prevent contamination (Price *et al.* 1986). The samples were maintained under low light conditions during all manipulations until the start of the incubation, usually within 1 h of sampling. Triplicate samples were taken for all depths except for the April 1997 samples where duplicates were only taken at two depths. Triplicate dark bottles were collected at the surface and incubated with the 100% I_o samples. A time zero sample was collected from the surface and filtered immediately after inoculation with $NaH^{14}CO_3$ onto each of a 0.7 μm and 5.0 μm filter.

The $NaH^{14}CO_3$ stock was stored refrigerated (5°C) but allowed to come to ambient temperature before inoculation of the samples. Samples were inoculated with 0.37 MBq (10 μCi) of $NaH^{14}CO_3$ New England Nuclear (NEC-086H) and incubated under natural light conditions in on-deck Plexiglas® incubators using neutral density screening to simulate the light levels from which the water was taken. The 100% I_o incubation bottles were placed in clear polycarbonate bags. No attempt was made to correct for spectral properties of incident light. Recirculating surface water controlled temperature within ±2°C. All incubations were ~6 h in duration except during May 1997 when incubations were 24 h in length.

A 100 μl sample of isotope stock was taken and added directly to scintillation vials containing 100 μl of ethanoalamine (Sigma Chemical Co.) which prevents $H^{14}CO_3$ from escaping to the atmosphere. This subsample was used to determine the total activity of ^{14}C added (DPM_{tot}). The incubations were terminated by gravity filtration through a cascade of a 47 mm, 5 μm Nuclepore® polycarbonate filter and then filtered through a 25 mm, Whatman® GF/F 0.7 μm filter using <100 mm Hg vacuum differential (Joint and Pomroy, 1983). The filters were gently sucked dry, rinsed with 15 ml of filtered seawater, folded and placed in a 20 ml scintillation vial. 250 μl of 0.5 N HCl was added to each vial to eliminate the unincorporated inorganic $NaH^{14}CO_3$ and the vials were placed uncapped in the fumehood until the filters were dry (approx. 24 h). The samples were stored in the dark until processing ashore.

At the onshore laboratory, 10 ml of Readysafe® scintillation fluor was added to the vials containing the filters. The vials were capped and stored in the dark for >24 h before the samples were counted on a Beckman® LS 6000 series liquid scintillation counter.

Primary productivity was determined from the amount of ^{14}C incorporated into particulate organic carbon and retained on a filter (Steemann-Nielsen, 1952; Parsons *et al.* 1984). Rates were calculated according to Parsons *et al.* (1984) to obtain mg C m^{-3} h^{-1}. A time zero blank correction was used for all calculations to correct for ^{14}C adsorption to the filters. Hourly primary productivity rates were converted to daily productivity by dividing the primary productivity by the percentage that the incubation period represented of the total daily irradiance. Light data were not available in October 1998 due to a datalogger failure. For conversion of October 1998 hourly primary productivity to daily primary productivity, the light data from October 1997 were used. Vertically integrated primary productivity was calculated by averaging the measured productivity between two depths and multiplying by the depth difference (Ichimura *et al.* 1980). The sum of these measurements yielded the hourly production integrated over depth and expressed as mg C m^{-2} h^{-1}. To evaluate the contribution of the >5 μm cells to the primary productivity, the >5 μm size fraction values were calculated as percentages of the total primary productivity. Dark bottles productivity rates were calculated but no dark bottle corrections were applied to the productivity values reported (Banse, 1993).

The carbon assimilation rate is the photosynthetic rate per unit of chlorophyll and was calculated by dividing the hourly productivity rates (mg C m^{-3} h^{-1}) by the chlorophyll concentration (mg chl m^{-3}). The integrated assimilation number was calculated by dividing integrated hourly productivity (mg C m^{-2} h^{-1}) by integrated chl concentration (mg chl m^{-2}).

Statistical analysis of chemical and biological data

Replicate casts were not completed due to time constraints in the cruise schedule and the labor-intensive nature of this study. Replicate (and sometimes triplicate) samples were routinely collected from each depth (i.e. from the same water sample) for analysis of size-fractionated chlorophyll and primary productivity. Replicate samples were only collected on glass fiber filters during April and July 1997. For the remainder of the cruises, replicate samples were collected on glass fiber filters and polycarbonate filters. The mean of the replicates is reported in this chapter.

One factor analysis of variance (ANOVA) and a Tukey test were used to examine spatial and temporal variation. For analysis of temporal variation, interannual and seasonal, the physical, chemical and biological data were grouped according to mean values for the WCVI and shelf and beyond shelf regions. For analysis of spatial variation, (i.e. the cross shelf and along shore direction), the data were grouped according to cruise and year.

RESULTS

The following sections will examine the distribution of biomass and productivity in space and time. Three spatial scales will be examined: the mean of all stations will be referred to as the mean for the west coast of Vancouver Island (WCVI); how biomass and productivity varies in a cross-shelf manner (West/East fashion) and how shelf and beyond shelf stations vary in an alongshore manner (from the southern La Pérouse transect to the northern Brooks Peninsula transect). Three time scales will also be examined for each spatial scale: a 2-yr mean (1997 and 1998); annual mean for 1997 and 1998; and a cruise mean.

Very high variability was observed for chlorophyll and primary productivity off the west coast of Vancouver Island. Trends and patterns will be discussed but the differences between regions, cruises, or years were not statistically significant unless otherwise noted.

A) Size-fractionated chlorophyll

Size-fractionated chlorophyll analysis allows one to determine which size fraction of phytoplankton was responsible for the measured changes in total chlorophyll. Integrated data ±1 S.D. from all stations sampled during 1997 and 1998 for size-fractionated chlorophyll were averaged for each cruise and for all 6 cruises and are given in Appendix J. The data are also stored in the Institute of Ocean Sciences Sidney, BC database. Vertical profiles of size-fractionated biomass are included in Appendix K.

A1) MEAN VALUES FOR WCVI

Annual and interannual means (WCVI)

The >5.0 μm size fraction contributed substantially to biomass on the WCVI (Figure 2.1). On average over the two year study period, the >5 μm fraction accounted for 46% of the total chlorophyll. The 2-yr mean biomass for all cruises was 31.0 mg chl m^{-2} for the <5 μm fraction and 39.8 mg chl m^{-2} for the >5 μm fraction.

In 1997, biomass was higher in the <5 μm fraction than the >5 μm fraction (Figure 2.1). The mean chlorophyll concentration for 1997 was 34.9 ±19.9 for the <5 μm fraction and was 30.6 ±35.7 mg chl m^{-2} for the >5 μm fraction. The relative contribution of the >5 μm fraction was greater in 1998 than in 1997. The mean chlorophyll concentration for 1998 was 27.1 ±15.7 in the <5 μm fraction relative to the 48.9 ±58.8 mg chl m^{-2} for the >5 μm fraction. In 1997, the >5 μm fraction accounted for 41% of the total chlorophyll, while in 1998 the large cells accounted for 50% of the total chlorophyll.

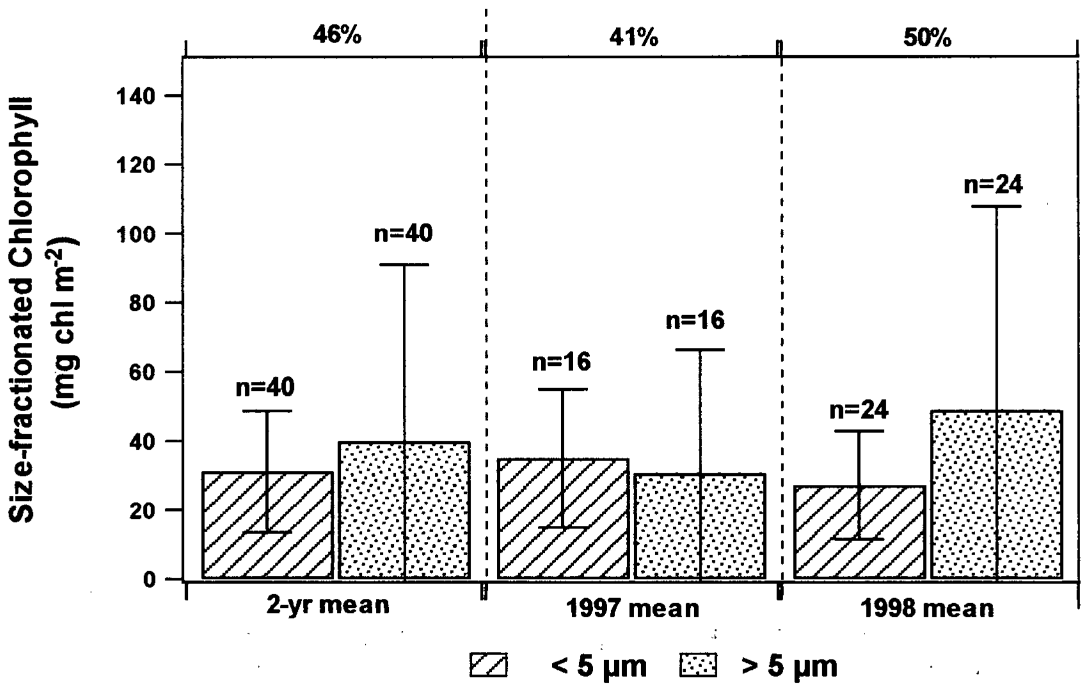

Figure 2.1 Interannual mean and annual means of size-fractionated chlorophyll ± 1 S.D. for the west coast of Vancouver Island in 1997 and 1998. Shelf and beyond shelf values are the mean of all shelf and beyond shelf stations, respectively. Numbers on the top of each panel represent the percentage of the total chlorophyll that was accounted for by the >5 µm fraction.

Seasonal means (WCVI)

The contribution of the >5 μm fraction was highest in April for 1997, while for 1998 the contribution of the >5 μm fraction was highest in July (Figure 2.2). The increase contribution seen in July 1998 was due to an increase in phytoplankton >5 μm since there was no seasonal change in biomass in the <5 μm size fraction.

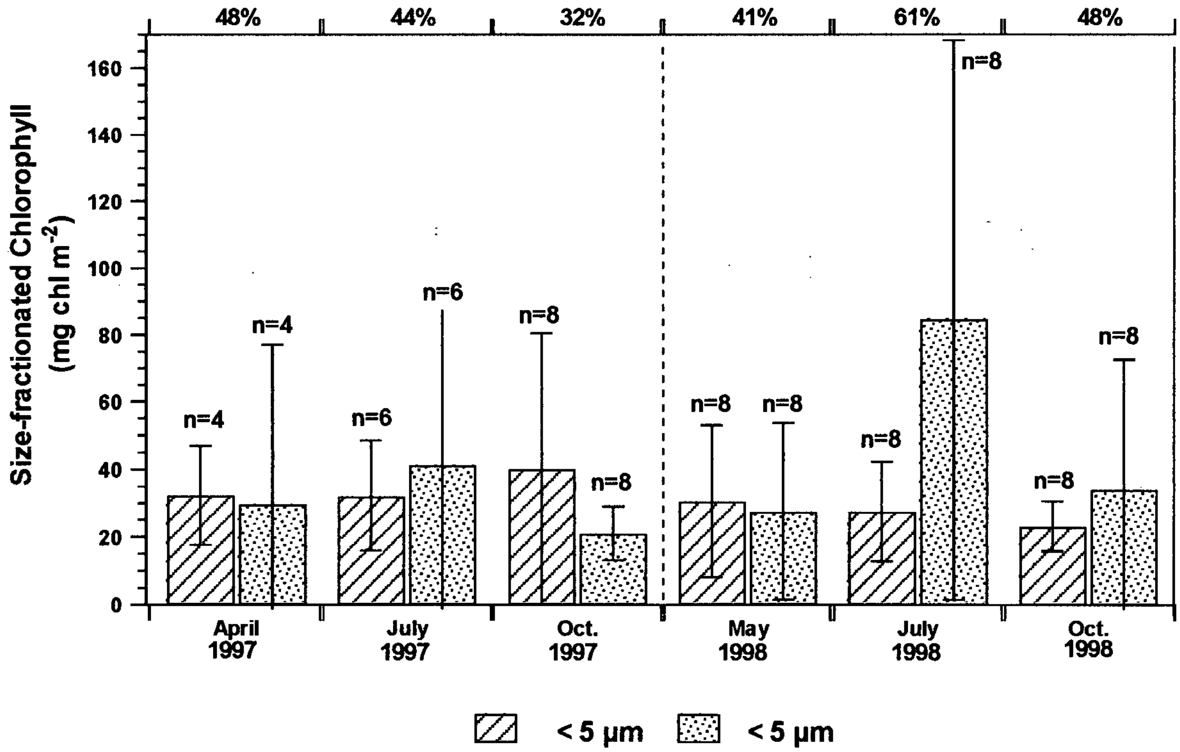

Figure 2.2 Cruise means of <5 μm and > 5 μm chlorophyll ± 1 S.D. for the west coast of Vancouver Island in 1997 and 1998. Values are the mean of shelf and beyond shelf stations during each cruise. Numbers on the top of each panel represent the percentage of the total chlorophyll that was accounted for by the >5 μm fraction.

A2) CROSS-SHELF GRADIENT

Annual and 2 yr means-cross-shelf

The size structure and the relative contribution of the >5 μm fraction was different in the shelf and beyond shelf regions. Phytoplankton biomass in the shelf region was dominated by the >5 μm fraction, whereas at the beyond shelf region, the <5 μm fraction accounted for the highest proportion of biomass (Figure 2.3). For the 2 year study period, large cells accounted for 62% (range between 23 and 82%) of total chlorophyll of the shelf regions while in the beyond shelf region they account for only 29% (range between 5 and 71%). The observed difference in the relative contribution of the >5 μm fraction between the two regions was significant ($p<0.01$).

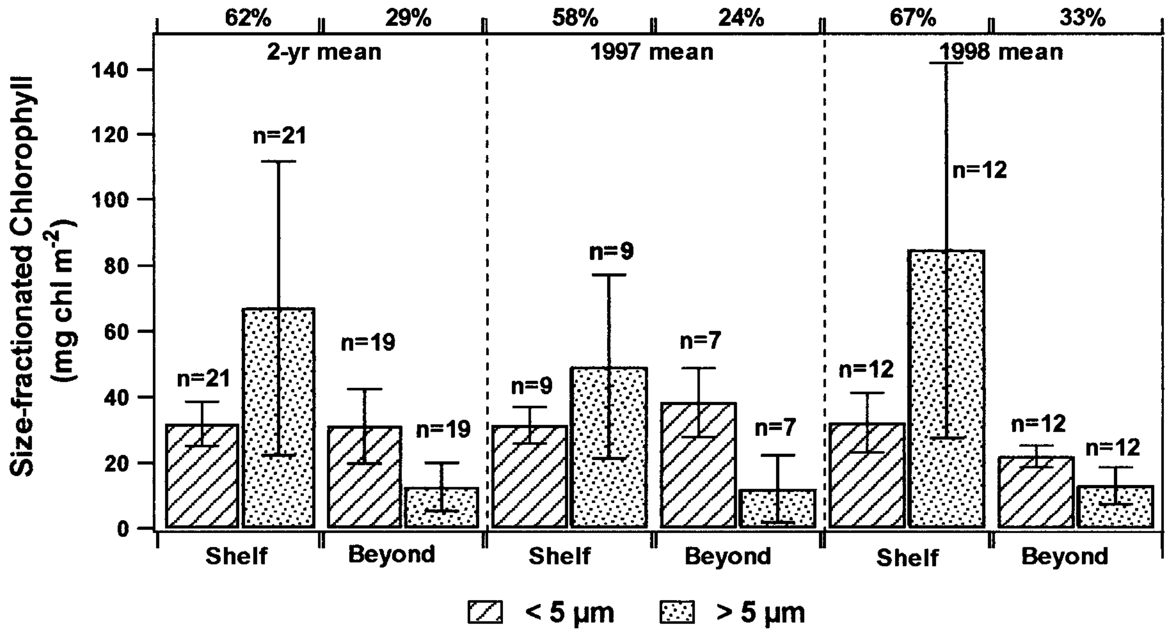

Figure 2.3 Interannual mean and annual means of size-fractionated chlorophyll ± 1 S.D. for the shelf and beyond shelf region off the west coast of Vancouver Island in 1997 and 1998. Shelf and beyond shelf means are the mean of all shelfand betond shelf stations sampled. Numbers on the top of each panel represent the percentage of the total chlorophyll that was accounted for by the >5 μm fraction.

In the shelf region, the difference between the two size fractions was not significant whereas in the beyond shelf region, biomass was significantly higher in the <5 μm fraction ($p<0.01$). The biomass in the <5 μm fraction showed little cross shelf variation while the >5 μm fraction showed significantly higher biomass in the shelf region than in the beyond shelf region ($p<0.01$).

Seasonal means-cross-shelf

In 1998, in the shelf region, the contribution of the >5 μm fraction increased relative to 1997. In 1998, chlorophyll in >5 μm fraction increased 1.7-fold relative to 1997, whereas the chlorophyll in <5 μm fraction remained the same (Figure 2.4).

The general pattern of higher biomass of the >5 μm fraction in shelf regions was evident during each cruise with the exception of the October 1997 cruise, when the small cells accounted for over 60% of the total chlorophyll (Figure 2.4). During all other cruises in 1997 and 1998, the >5 μm fraction accounted for the majority of the total biomass of shelf region whereas the <5 μm accounted for the majority of total biomass in beyond shelf regions. There was no consistent seasonal pattern for the relative contribution of the >5 μm fraction. For 1997, the relative contribution of the >5 μm fraction was similar in April and July, while for 1998 the relative contribution was highest in July .

Seasonal changes in biomass and the lack of a consistent seasonal pattern in the relative contribution of the >5 μm fraction, suggest variable environmental conditions over the course of the season. The highest contribution of the >5 μm fraction during the two study years was in July 1998.

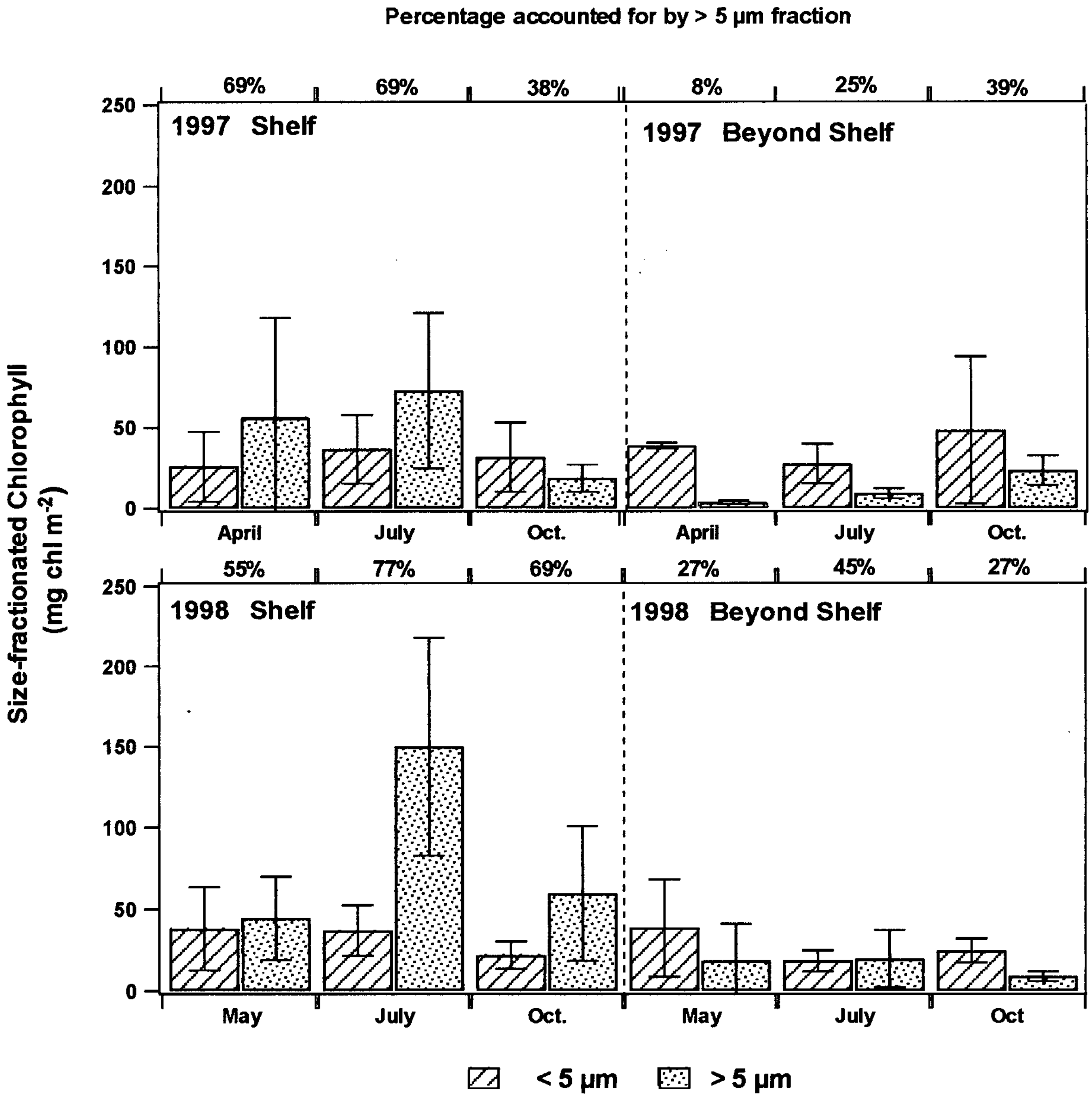

Figure 2.4 Mean of size-fractionated chlorophyll ± 1 S.D. for the shelf and the beyond shelf region off the west coast of Vancouver Island in April (n=2), July (n=3) and October 1997 (n=4) and May (n=4), July (n=4) and October (n=4) 1998. Shelf and beyond shelf values are the mean of all shelf and beyond shelf stations. Numbers on the top of each pannel represents the precentage of the total chlorophyll that was accounted for by the >5 µm fraction.

Transects-cross shelf

The highest biomass for the >5 μm fraction was measured in July 1997 at Barkley Canyon. In 1998 the highest biomass was measured in July at Brooks Peninsula but high biomass was also observed at La Pérouse Bank and Estevan Point (Appendix K). In 1998, high biomass was measured in the shelf region of most transects suggesting all transects have the potential of favorable conditions for phytoplankton growth. The minimum for both size fractions was observed in 1997 whereas the maximum concentration for both fractions was observed in 1998. This fact coupled with a slightly higher contribution of large cells suggests that 1998 was a better growing year than 1997.

Variability

Size-fractionated biomass on the WCVI showed high variability on average, with a range of 8.7-80.0 mg chl m^{-2} for the <5 μm fraction and 1.8-213.1 mg chl m^{-2} for the >5 μm fraction. The relative contribution of the large size fraction also varied widely from a low of 5% to a high of 82% of the total chlorophyll.

A3) DEPTH PROFILES OF SIZE-FRACTIONATED CHLOROPHYLL

The relative contribution of the >5 μm fraction varied with depth in the water column in both the shelf and the beyond shelf regions (Figure 2.5 and 2.6). Only the values for July 1997 and 1998 are shown; the values for the remaining cruises are shown in Appendix L. The trends were clearer in 1998 than in 1997, but they showed that generally the contribution of the >5 μm fraction decreases with depth.

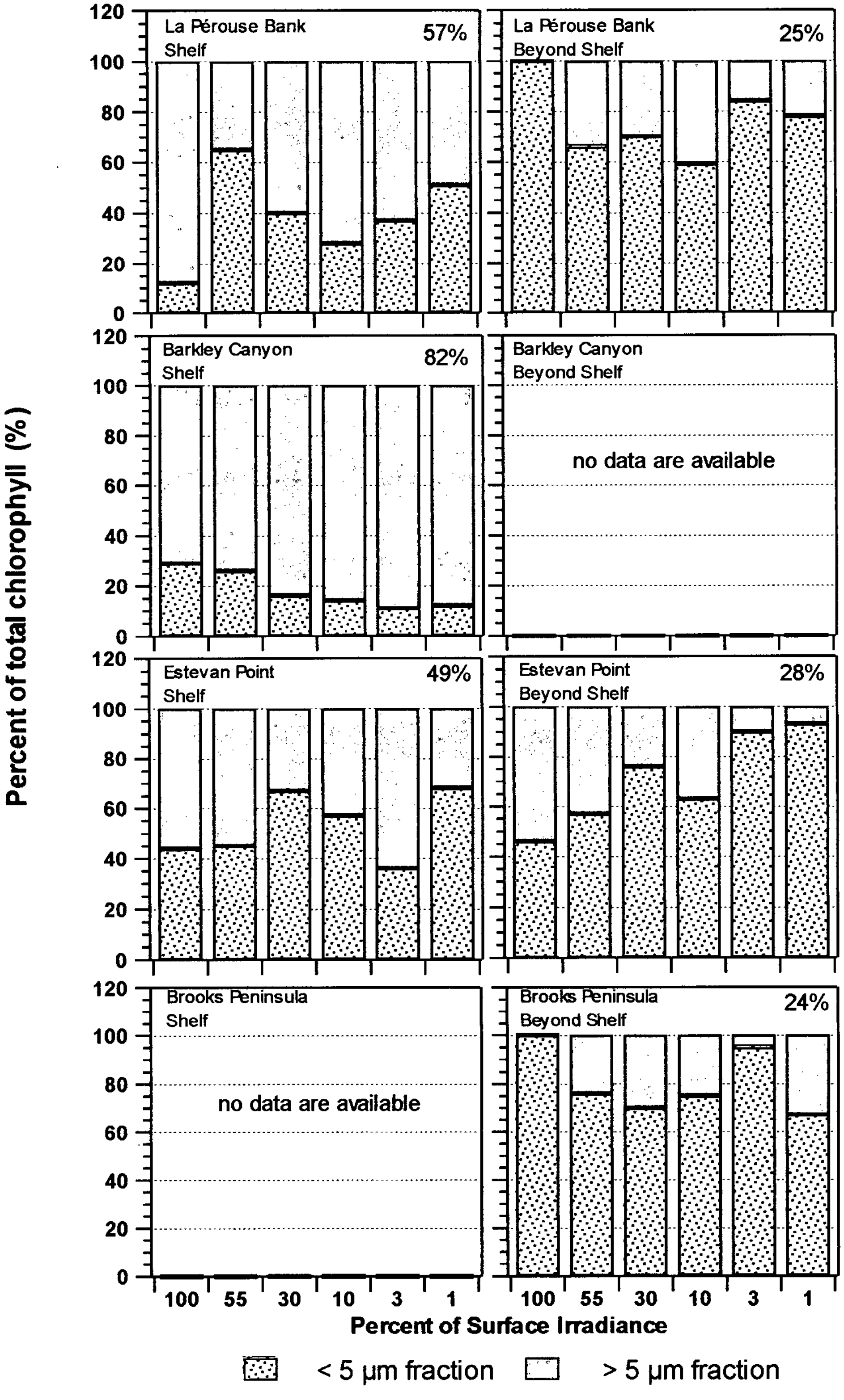

Figure 2.5 Relative contribution of < 5.0 µm size fraction and > 5.0 µm size fraction to chlorophyll at each light depth for the shelf and the beyond shelf station of each transect during July 1997. Relative contribution of > 5.0 µm fraction to depth integrated chlorophyll is in right hand corner of each graph. Brooks Peninsula shelf and Barkley Canyon beyond shelf stations were not sampled.

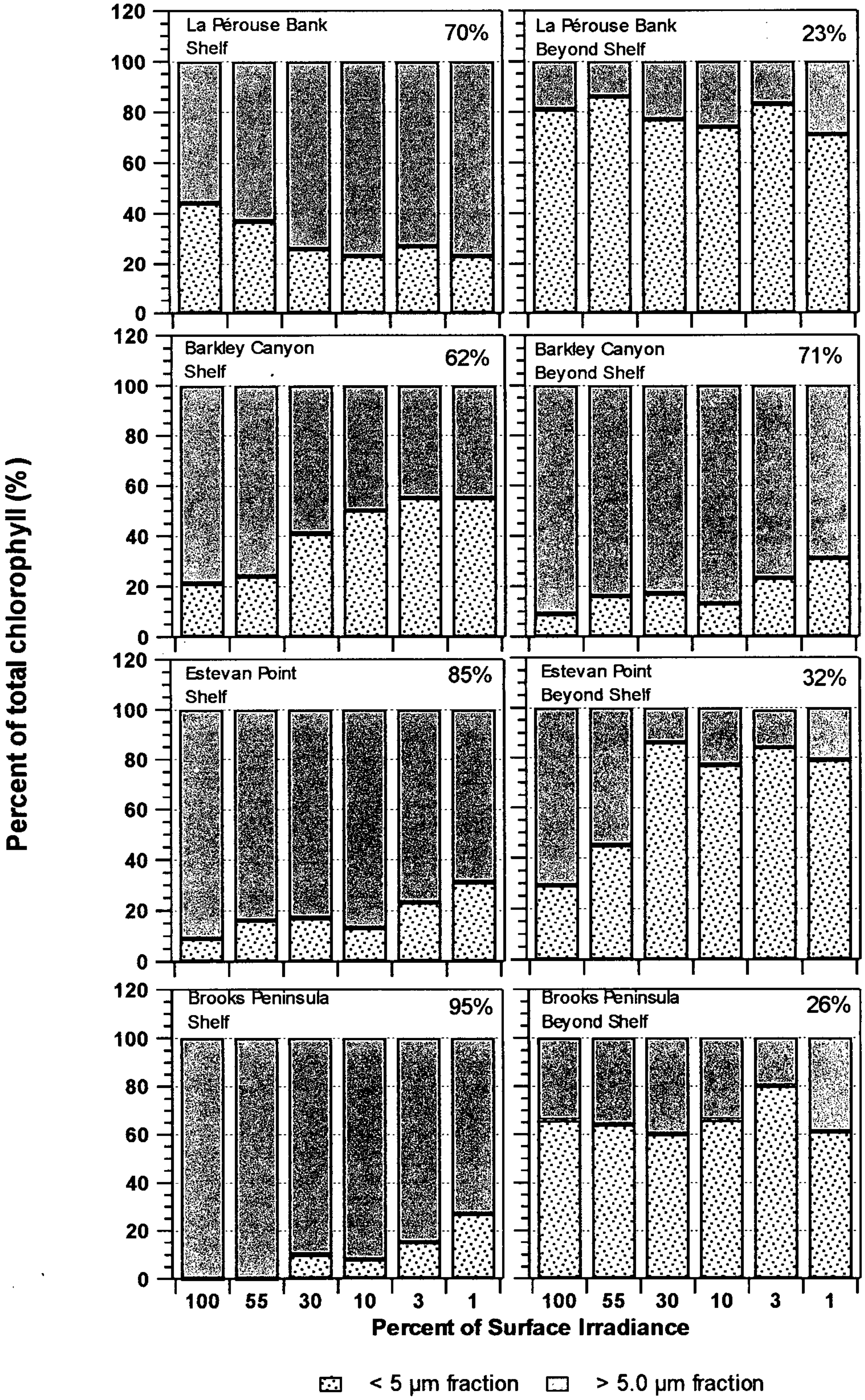

Figure 2.6 Relative contribution of <5 µm size fraction and >5 µm size fraction to chlorophyll at each light depth for the shelf and the beyond shelf station of each transect during July 1998. Relative contribution of >5 µm fraction to depth integrated chlorophyll is in the right hand corner of each graph.

B) Total Primary Productivity

Integrated primary productivity data for all stations during 1997 and 1998 averaged for each cruise, each year and for all 6 cruises (2 yr mean) are given in Appendix M. For this section, total and size-fractionated primary productivity will be discussed separately.

B1) WCVI-TOTAL PRODUCTIVITY

The 2 yr mean primary productivity for the WCVI was 4.0 ±0.8 g C m^{-2} d^{-1} (range between 0.8 and 5.7 g C m^{-2} d^{-1}). In 1997, primary productivity was on average higher (4.3 g C m^{-2} d^{-1}) than in 1998 (3.4 g C m^{-2} d^{-1}).

There was no consistent seasonal pattern in primary productivity during the two years except during both study years the lowest productivity was measured always in October (Figure 2.7). In 1997, primary productivity was highest in April, while in 1998 primary productivity was highest in July.

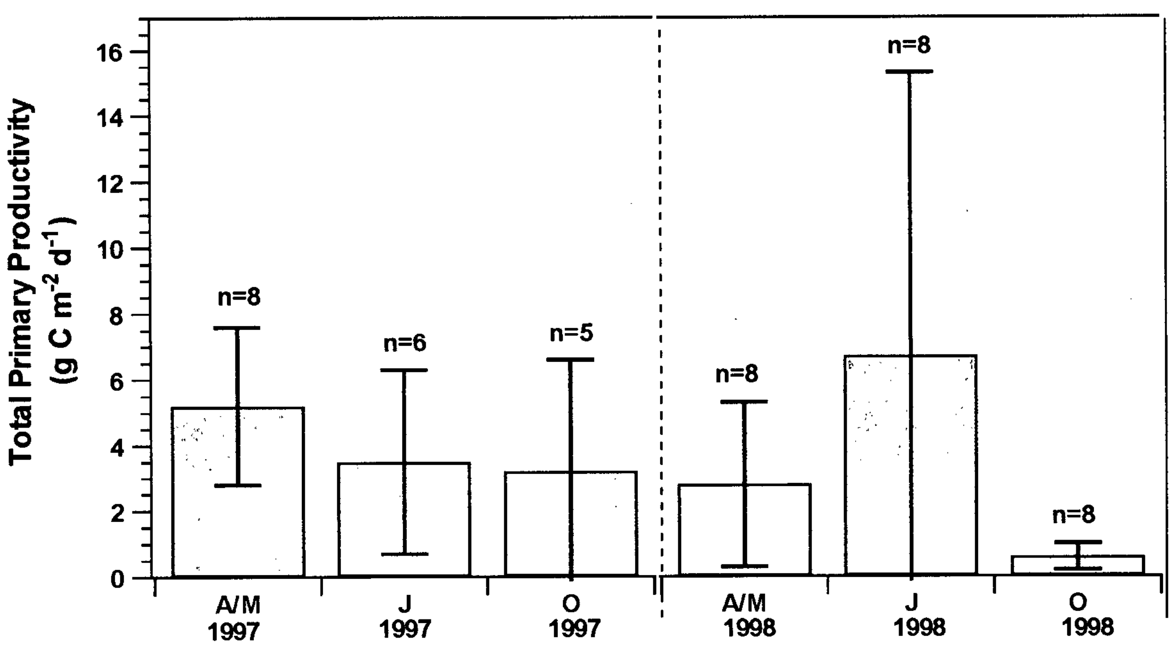

Figure 2.7 Daily mean primary productivity ± 1 S.D. off the west coast of Vancouver Island for April, July and October 1997 and May, July and October 1998. Values are the mean of all stations sampled during each cruise.

B2) CROSS-SHELF GRADIENT

2 yr mean and annual means

Primary productivity was generally higher in the shelf than the beyond shelf region (Figure 2.8). The 2 yr mean primary productivity was 5.1 ±2.7 and 2.0 ±0.1 g C m^{-2} d^{-1} in the shelf and beyond shelf region. On average over the study period, primary productivity was 2.6-fold higher in shelf regions than beyond shelf regions. During 1997, the difference between shelf and beyond shelf regions was less clear than in 1998. Primary productivity was on average 1.8-fold higher in shelf regions in 1997, whereas in 1998 primary productivity was 4.0-fold higher.

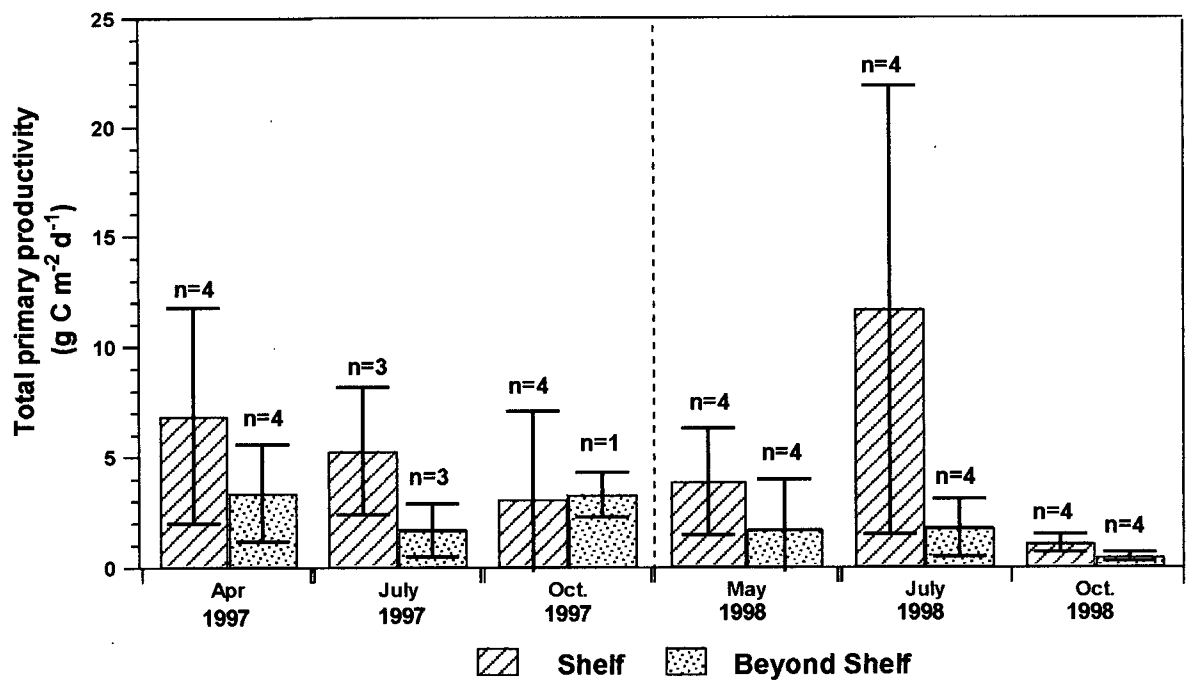

Figure 2.8 Mean primary productivity ± 1 S.D. (g C m^{-2} d^{-1}) of the shelf and the beyond shelf regions off the west coast of Vancouver Island in 1997 and 1998. Shelf and beyond shelf means are the average of all shelf and beyond shelf stations sampled.

Seasonal means

The general trend of higher primary productivity in the shelf region was not observed during October 1997 or July 1998 when the primary productivity was slightly higher in the beyond shelf region of the Brooks Peninsula transect (Figure 2.9). The maximum difference between the two regions occurred in July 1998 when productivity was 6.5-fold higher in the shelf. No consistent seasonal pattern was observed in either the shelf or the beyond shelf region. For 1997, primary productivity in the shelf region was highest during April, while in 1998 the seasonal peak occurred in July.

Variability

Both regions showed high variability on average, with a range between 0.6 and 26.1 g C m^{-2} h^{-1} for the shelf region and 0.3 and 6.3 g C m^{-2} h^{-1} for the beyond shelf region. The variability in primary productivity during both years was similar in the shelf and the beyond shelf regions.

B3) ALONGSHORE DIRECTION

There was no consistent pattern along the length of Vancouver Island in shelf or beyond shelf regions for 1997 or for 1998 (Figure 2.9). The transect where biomass was the highest varied with each cruise. No alongshore gradient in primary productivity was observed for 1997 and 1998.

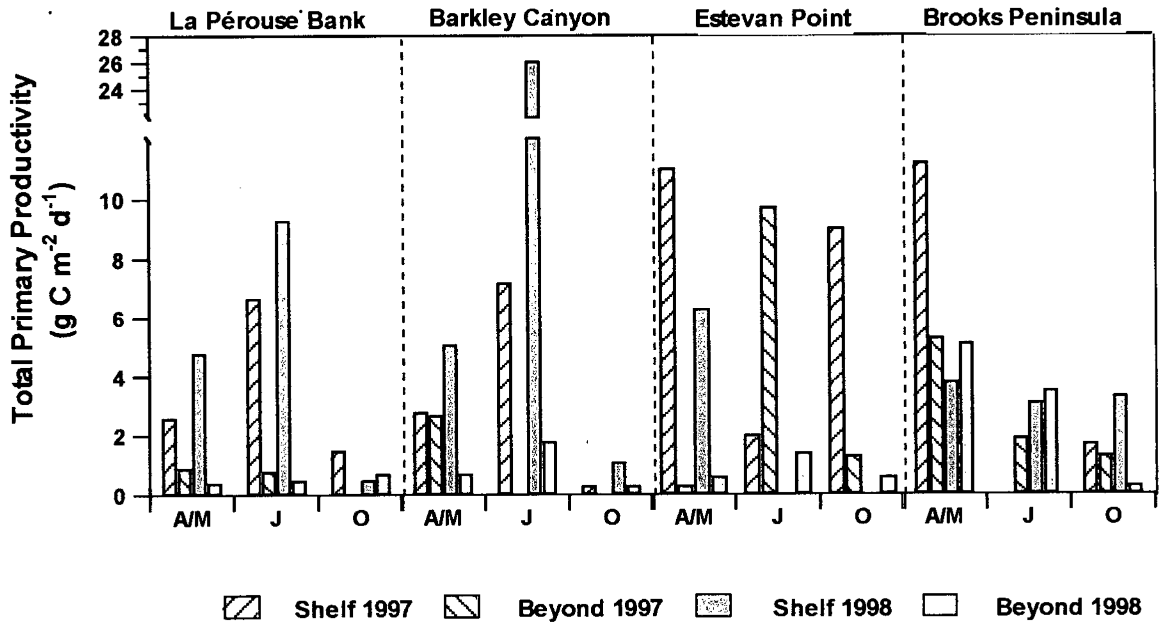

Figure 2.9 Total mean primary productivity of shelf and beyond shelf regions of the La Pérouse Bank, Barkley Canyon, Estevan Point and Brooks Peninsula transect off the west coast of Vancouver Island. One station was sampled for each of the shelf and the beyond shelf region of each transect. A/M=April and May, J=July and O=October.

C) Size-fractionated primary productivity

Integrated data ±1 S.D. from all stations sampled during 1997 and 1998 for size-fractionated primary productivity were averaged for each cruise and for all 6 cruises and are given in Appendix M.

C1) WCVI-SIZE-FRACTIONATED

2 year means

Productivity was consistently higher in the >5 μm fraction than in the <5 μm fraction for 1997 and 1998 (Figure 2.10). The 2 yr mean primary productivity was 1.1 ±0.6 and 2.8 ±0.7 g C m^{-2} d^{-1} for the <5.0 μm and >5.0 μm fraction, respectively. On average, primary productivity in the >5.0 μm fraction was 2.5-fold higher than productivity in the <5.0 μm fraction. On average, the >5 μm fraction accounted for 54% of the total primary productivity of the WCVI. Primary productivity of both size fractions was on average higher in 1997 than in 1998 (Figure 2.10).

Size-fractionated primary productivity on the WCVI showed high variability on average, with a range of 0.3-1.8 g C m^{-2} d^{-1} for the <5.0 μm fraction and 0.4-5.4 g C m^{-2} d^{-1} for the >5.0 μm fraction. Variability was higher in 1998 than 1997 for both size fractions (coefficient of variation = 26 and 73% for <5 μm fraction for 1997 and 1998, respectively and 26 and 93% for the >5 μm fraction for 1997 and 1998, respectively). The relative contribution of the >5 μm fraction varied widely from a low of 44% to a high of 62% of the total primary productivity. Clearly the >5.0 μm fraction contributed substantially to primary productivity on the WCVI.

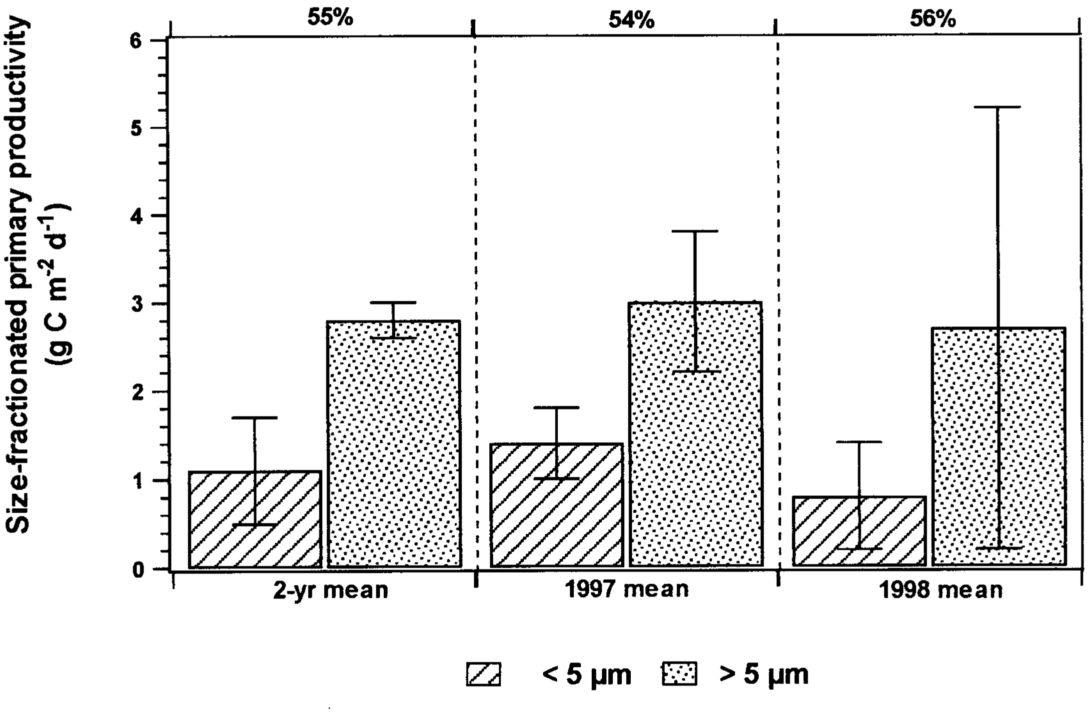

Figure 2.10 Interannual mean and annual means of size-fractionated primary productivity ± 1 S.D. for the west coast of Vancouver Island in 1997 and 1998. Number on the top of each panel represent the percentage of the total primary productivity that was accounted for by the >5 μm fraction.

Seasonal means

There was no consistent seasonal trend in primary productivity for either fraction. For 1997, productivity was highest in April and for 1998, it was the highest in July (Figure 2.11). The highest productivity of the two years was measured in the >5 μm fraction in July 1998.

There was no consistent seasonal pattern of the relative contribution of the >5.0 μm size fraction during 1997 and 1998. The relative contribution of the > 5 μm fraction was similar in 1997 and 1998, but was more variable in 1998 than 1997 (coefficient of variation in 1997 was 3% and in 1998 was 18%).

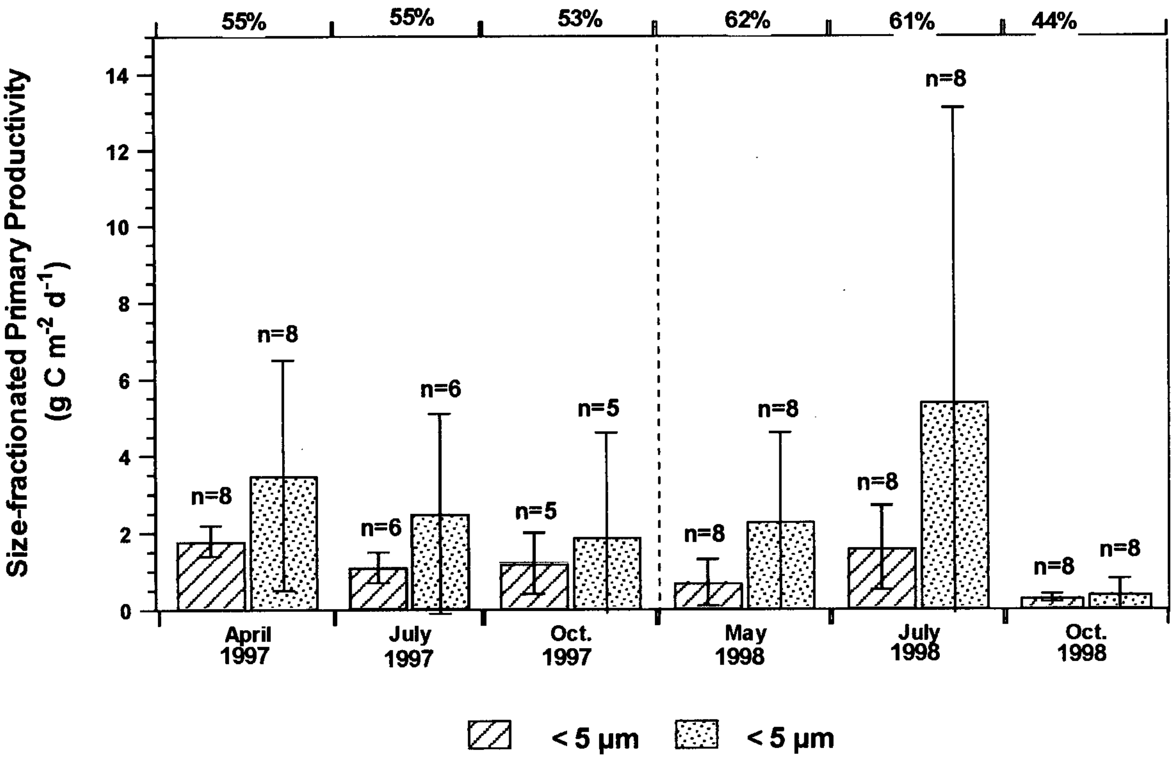

Figure 2.11 Cruise means of <5 μm and > 5 μm primary productivity ± 1 S.D. for the west coast of Vancouver Island in 1997 and 1998. Values are the mean of shelf and beyond shelf stations during each cruise. Numbers on the top of each panel represent the percentage of the total primary productivity that was accounted for by the >5 μm fraction.

C2) CROSS-SHELF GRADIENT

2 year means

Generally, the size structure of primary productivity of the two regions was different. In the shelf regions, primary productivity was dominated by >5 μm phytoplankton while at the beyond shelf region <5 μm phytoplankton accounted for the highest proportion of productivity (Figure 2.12). The >5 μm phytoplankton accounted for on average 72% (range between 67 and 86%) of total primary productivity of the shelf regions and only 36% (range between 23 and 75%) for the beyond shelf regions. Shelf region primary productivity of the >5 μm fraction was significantly greater than the productivity of the <5 μm fraction ($p<0.05$). Productivity in the >5 μm fraction was significantly higher in the shelf than in the beyond shelf region (Figure 2.12) There was no consistent trend in productivity for the <5 μm fraction and on average productivity was similar in both regions.

Variability

The variability in the shelf region was higher in the <5 μm fraction than the >5 μm fraction, in contrast to higher variability in the >5 um fraction than the <5 μm fraction in beyond shelf regions (see coefficient of variation in Appendix M) The variability of the >5 μm fraction was similar in both regions. For the <5 μm fraction variability was higher in the shelf than beyond the shelf. This implies that primary productivity in the small cells in the beyond shelf region is static while in the shelf region it undergoes changes and is dynamic. On average, variability was higher in 1998 than 1997 for both fractions and both regions.

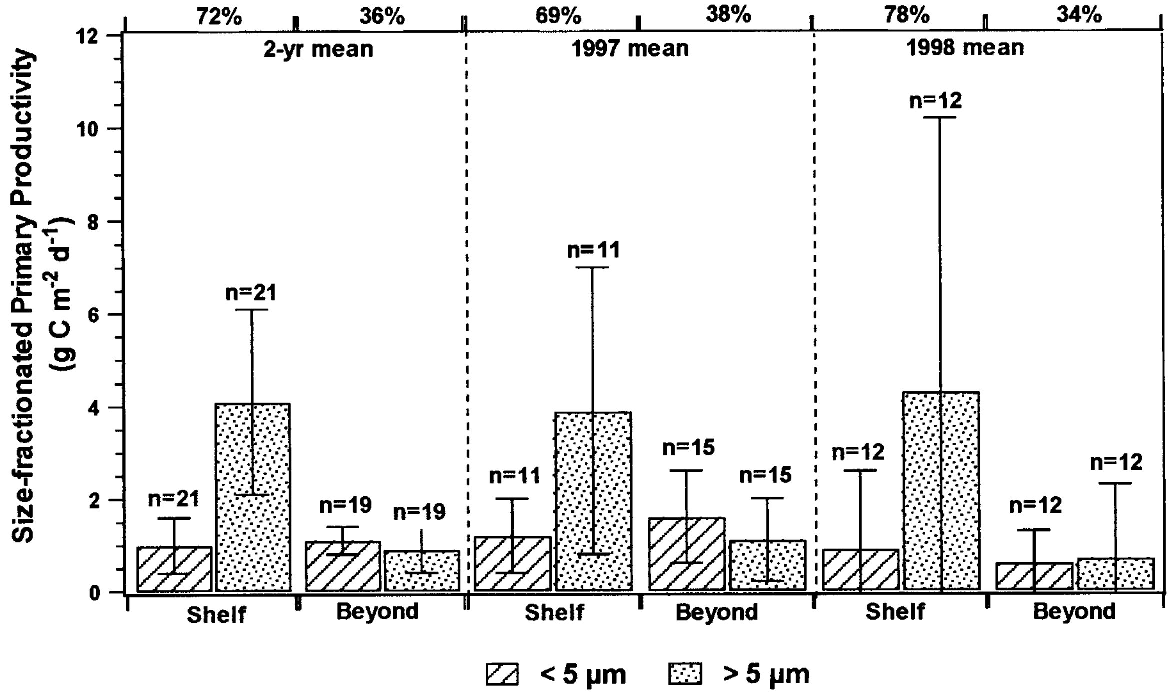

Figure 2.12 Interannual mean and annual means of size-fractionated primary productivity ± 1 S.D. for the shelf and beyond shelf region off the west coast of Vancouver Island in 1997 and 1998. Shelf and beyond shelf means are the mean of all shelfand betond shelf stations sampled. Numbers on the top of each panel represent the percentage of the total primary productivity that was accounted for by the >5 μm fraction.

Seasonal Means

The general pattern of higher contribution of the >5 μm fraction relative to the <5 μm fraction was not always observed; in October 1997, the <5.0 μm fraction accounted for 59% of the primary productivity at La Pérouse Bank. The relative contribution of the >5.0 μm fraction in the shelf region was lowest in October in 1997 and 1998. This suggests that environmental conditions were not favorable for >5 μm phytoplankton in the fall. There was no consistent seasonal trend in the beyond shelf region of the relative contribution of the >5 μm fraction during 1997 and 1998 (Figure 2.13). A trend may be obscured by the fact that in October 1997 only one beyond shelf station (Brooks Peninsula) was sampled and during May 1998 the phytoplankton community at Brooks Peninsula beyond the shelf was more typical of a shelf region. The highest productivity of the two years was measured in the shelf region in the >5 μm fraction in July 1998.

Variability

In 1997, the variability was greater in the >5 μm fraction than the <5 μm fraction in contrast to higher variability in the <5 μm fraction in 1998. In 1997, the coefficient of variation was 79% for the >5 μm fraction and 66% for the <5 μm fraction. In 1998, the coefficient of variation was 138% for the >5 μm fraction and 201% for the <5 μm fraction.

The pooled data clearly show that the contribution of the >5 μm size fraction was greater at high biomass concentrations and high productivity rates, supporting the idea that in order to reach high biomass and productivity, large cells are required (Figure 2.14). The lack of data points in the bottom right hand corner show that high rates of primary productivity were not measured if large phytoplankton were not abundant. The pooled data also clearly shows the distinct characteristics of shelf and the beyond shelf regions. Generally, beyond shelf stations are grouped at the bottom left hand quadrant and are characterized by low total chlorophyll composed mainly of small cells and by lower productivity, also accounted for by the smaller cells. During the two years of this study, beyond shelf stations were never found in the top right hand quadrant.

C3) DEPTH PROFILES OF THE CONTRIBUTION OF >5 μm FRACTION

In the shelf region, the relative contribution of the >5 μm fraction was highest at the top of the euphotic zone and then decreased as the depth increased (Figure 2.15 and 2.16). The relative contribution of the <5 μm fraction generally increased as depth. At the beyond shelf region, the <5 μm fraction was generally high at all depths with a slight increase at the bottom of the euphotic zone.

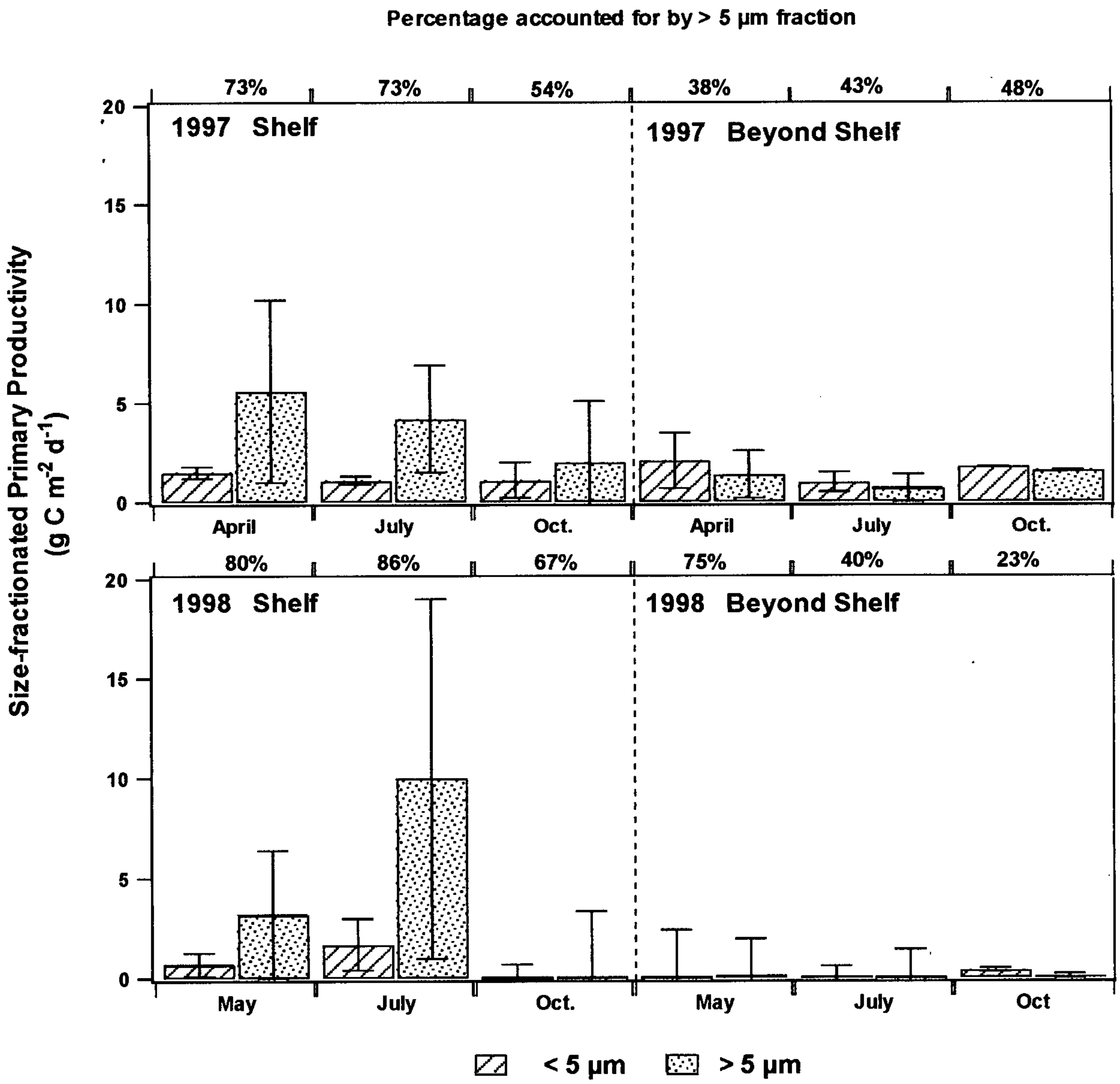

Figure 2.13 Mean of size-fractionated primary productivity ± 1 S.D. for the shelf and the beyond shelf region off the west coast of Vancouver Island in April (n=2), July (n=3) and October 1997 (n=4) and May (n=4), July (n=4) and October (n=4) 1998. Shelf and beyond shelf values are the mean of all shelf and beyond shelf stations. Numbers on the top of each pannel represents the precentage of the total primary productivity that was accounted for by the >5 µm fraction.

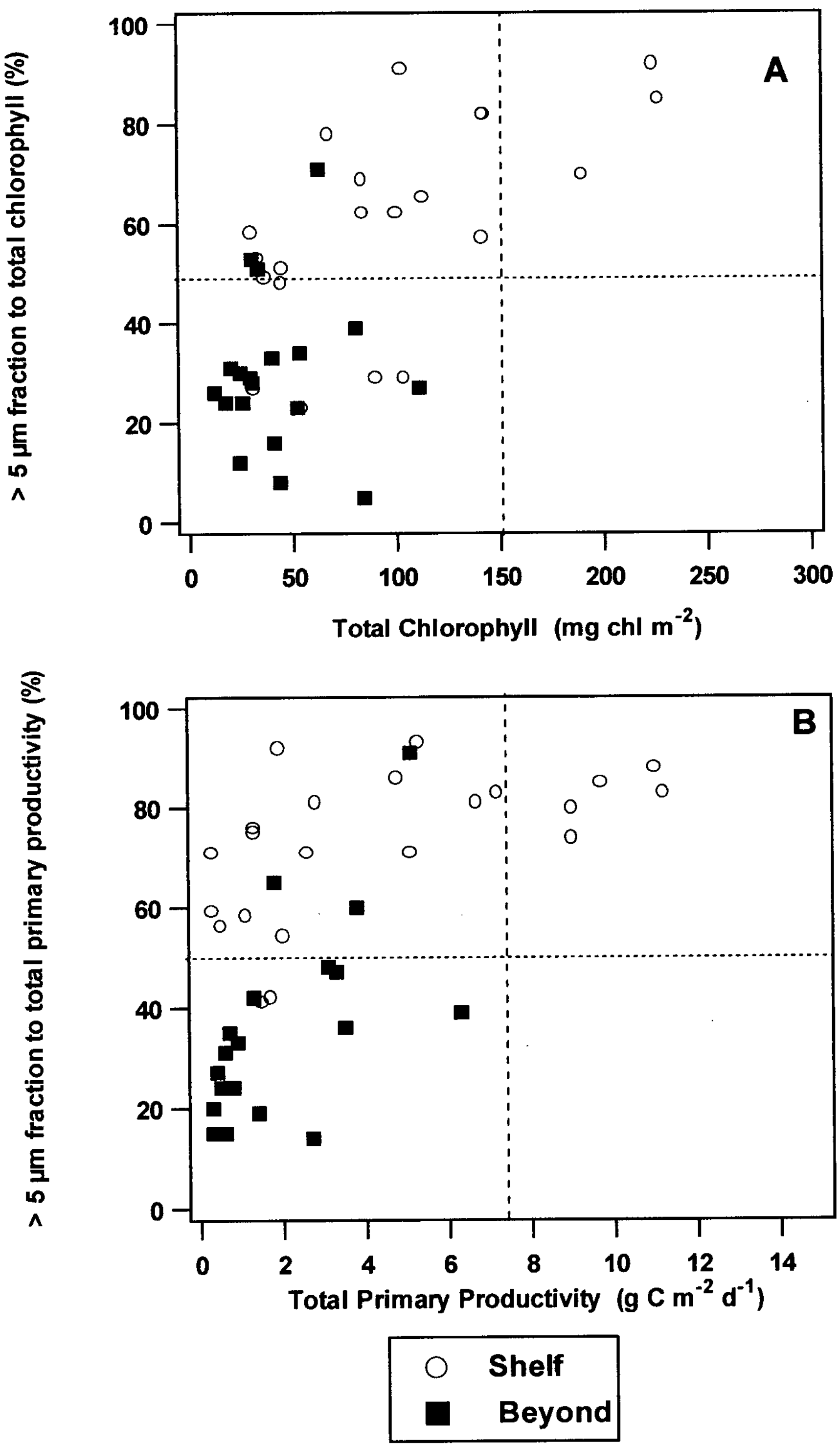

Figure 2.14 Percent contribution of >5 µm size fraction relative to: A) total chlorophyll and B) total primary productivity off the west coast of Vancouver Island. Values are for all stations in 1997 and 1998 in the shelf and the beyond shelf region.

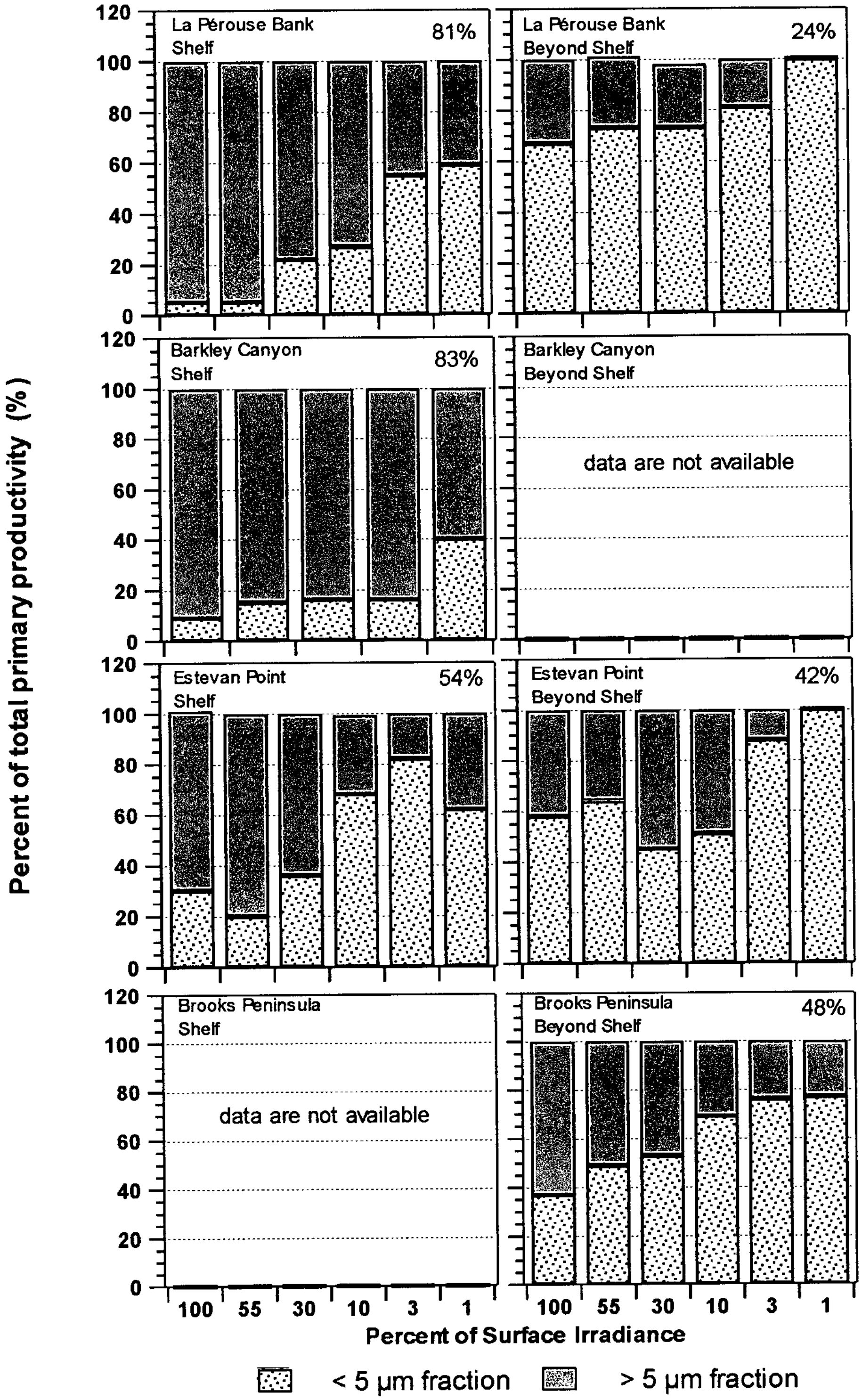

Figure 2.15 Relative contribution of < 5 μm size fraction and > 5 μm size fraction to primary productivity at each light depth for the shelf and the beyond shelf station of each transect during July 1997. Relative contribution of > 5 μm fraction to depth integrated primary productivity is inthe right hand corner of each graph. Brooks Peninsula shelf and Barkley Canyon beyond shelf stations were not sampled.

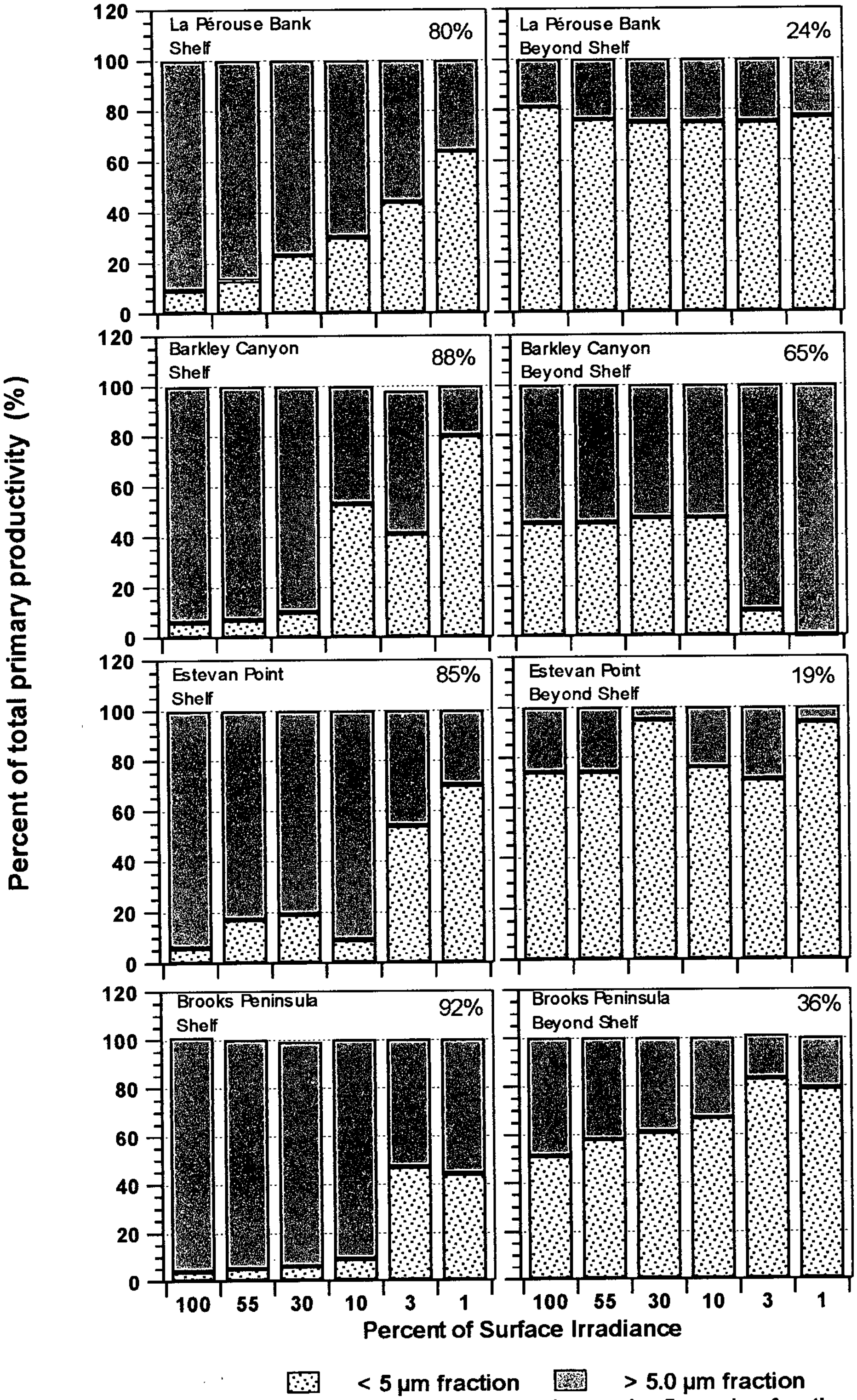

Figure 2.16 Relative contribution of < 5 µm size fraction and > 5 µm size fraction to primary productivity at each light depth for the shelf and the beyond shelf station of each transect during July 1998. Relative contribution of > 5 µm fraction to depth integrated primary productivity is in the right hand corner of each graph.

D) CARBON ASSIMILATION RATES

D1) MEAN VALUES FOR WCVI

The 2 yr mean carbon assimilation rates for the WCVI were 4.0 ±0.8 g C mg chl^{-1} d^{-1} (range between 1.8 and 4.9). Carbon assimilation rates were on average similar in 1997 (4.4 g C mg chl^{-1} d^{-1}) and 1998 (3.8 g C mg chl^{-1} d^{-1}). There was no consistent seasonal pattern in carbon assimilation rates during the two years except during both study years the highest rates were measured in July (Figure 2.17). Variability was higher in 1998 than in 1997 (coefficient of variation in 1998=46% and in 1997=6%).

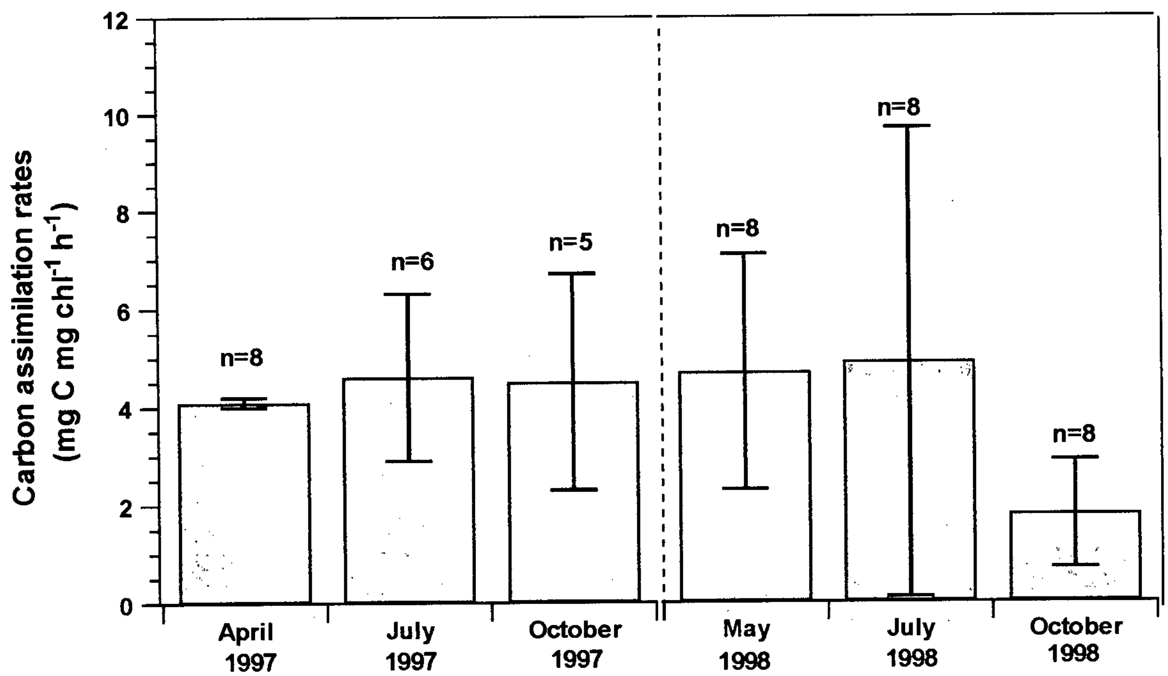

Figure 2.17 Carbon assimilation rates ± 1 S.D. off the west coast of Vancouver Island in 1997 and 1998. Values are the mean of all stations sampled during each cruise.

D2) CROSS-SHELF GRADIENT

Carbon assimilation rates were on average higher in the shelf region than beyond the shelf (Figure 2.18). The 2 yr assimilation rates were 4.1 ±0.8 and 3.8 ±1.1 g C mg chl^{-1} d^{-1} in the shelf and beyond shelf regions, respectively. No consistent seasonal pattern was observed for the shelf or the beyond shelf regions. Carbon assimilation rates in the shelf region were higher in 1997 than in 1998, while in the beyond shelf region rates were similar in both years. The differences between values in the shelf region were not significantly different from each other. During 1997 and 1998, the variability was higher in the beyond shelf region than the shelf region.

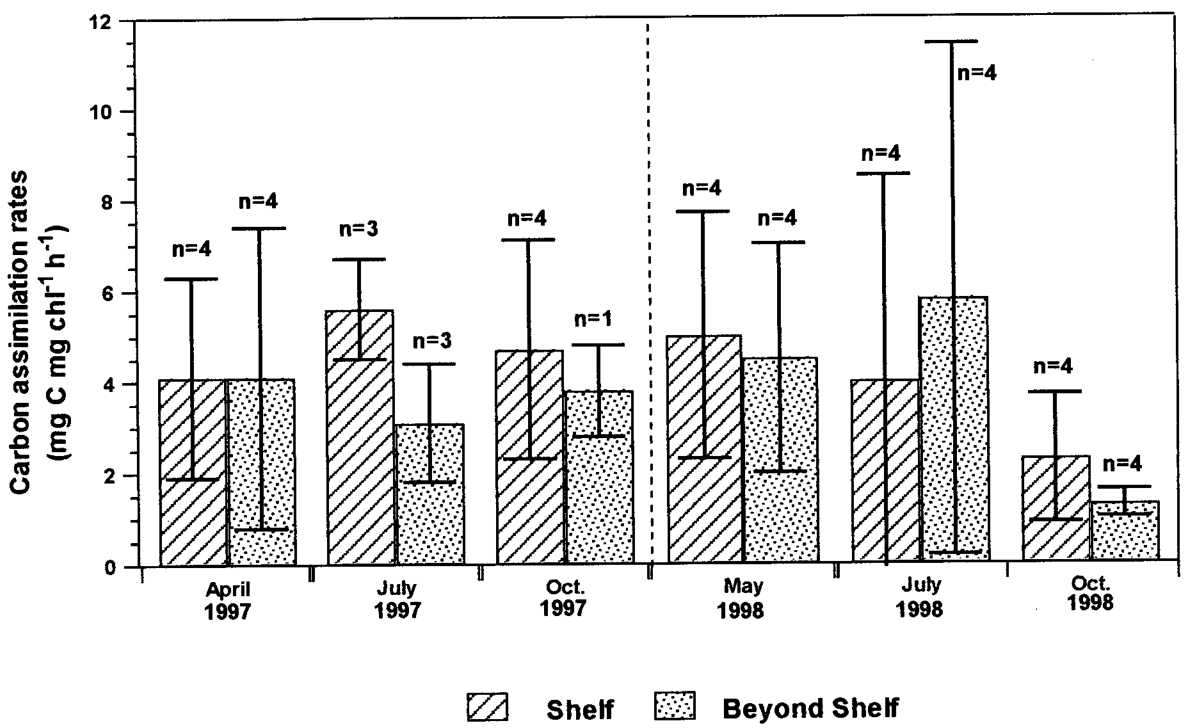

Figure 2.18 Carbon assimilation rates ± 1 S.D. of the shelf and the beyond shelf regions off the west coast of Vancouver Island in 1997 and 1998. Shelf means are the average of all shelf stations sampled during each cruise and beyond shelf values are the mean of all beyond shelf stations during each cruise.

D3) ALONGSHORE GRADIENT

There was no trend along the length of Vancouver Island for the shelf region for the 2 yr mean. Carbon assimilation rates were on average highest at Barkley Canyon and lowest at Estevan Point, but the differences between transects were not significant. The location of the peak carbon assimilation rate during each of the three cruises in 1997 and 1998 did not show a consistent pattern (Figure 2.19) and varied during each cruise and each year. In the beyond shelf region, there was a trend for assimilation rates to increase progressively from La Pérouse Bank to Brooks Peninsula during each cruise in 1997 and 1998.

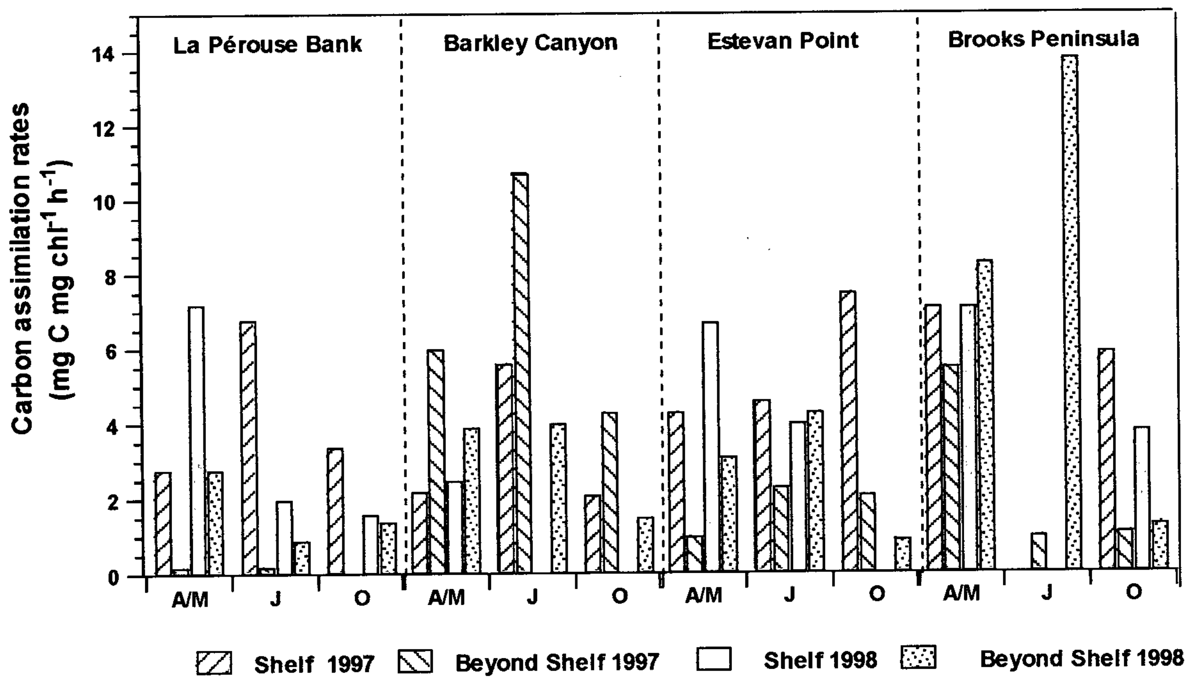

Figure 2.19 Carbon assimilation rates of the shelf and the beyond shelf region of La Pérouse Bank, Barkley Canyon, Estevan Point and Brooks Peninsula transect off the west coast of Vancouver Island in 1997 and 1998. Shelf and beyond means are the average of all shelf and beyond shelf stations, respectively.

Table 2.1 Summary of characteristics of shelf and beyond shelf regions off the west coast of Vancouver Island. Values are for 1997 and 1998. Units for parameters below are: ML, meters; temperature, °C, nitrate, µM; chlorophyll, mg m^{-2}; PP, mg C m^{-2} d^{-1}; carbon assimilation rates, mg C mg chl^{-1} h^{-1}; CV, %)

		Shelf	**Beyond Shelf**
Mixed Layer depth		11.8	23.2
Mixed layer temperature		11.85	12.75
Mixed layer salinity		31.1	31.5
NO_3		6.1	2.4
Total Chlorophyll	range	24.3-226.7	11.9-147.8
	97/98 Mean	95.6	49
	Median	84.1	36.7
<5 µm chlorophyll	range	10.4-73.9	8.7-48.8
	97/98 Mean	32.2	26.7
>5 µm chlorophyll	range	12.3-213.1	3.0-44.5
	97/98 Mean	59.8	13.5
% contribution	range	23-92	5-71
	97/98 Mean	62	29
Total PP	range	0.3-26.1	0.3-5.1
	97/98 Mean	5.1	2.0
	Median	2.8	0.9
	C.V.	52	4
<5 µm PP	range	0.1-3.2	0.2-3.8
	97/98 Mean	1.0	1.1
>5 µm PP	range	0.2-22.9 *	0.1-4.6
	97/98 Mean	4.1	0.9
% contribution	range	41-93	14-91
	97/98 Mean	72	36
AN	range	1.0-10.7	0.2-13.8
	97/98 Mean	4.2	3.8

* 0-9.7 when one station was excluded

DISCUSSION

Distribution of biomass and primary productivity

Total phytoplankton biomass and primary productivity off the west coast of Vancouver were high. Surface biomass reached 13.4 mg chl m^{-3} and mean integrated chlorophyll biomass up to 227 mg chl m^{-2} was measured. Total chlorophyll greater than 100 mg chl m^{-2} and primary productivity >5 g C m^{-2} d^{-1} was frequently measured during all cruises. During most cruises primary productivity > 3 g C m^{-2} d^{-1} was common. On average, primary productivity was 4.0 g C m^{-2} d^{-1} off the west coast of Vancouver Island.

On average, biomass was higher in 1998 than in 1997, while on average primary productivity was lower in 1998 than in 1997, mainly due to differences in the beyond shelf region. Whitney *et al.* (1998) have shown a shoaling and warming of the mixed layer depth in the 1990's and consequently reduced NO_3^- concentrations in the surface layer. Strong vertical stratification of the water column would effectively block the vertical flux of nutrients to the surface. Chapter one showed surface depletion of NO_3^- and a deeper mixed in 1998 layer suggesting nutrient availability may have accounted for some of the difference in primary productivity between the two years. Alternately, the role of solar radiation can not be ruled out since we do not have solar radiation for the full growing season. Solar radiation was only collected during the duration of the cruise and consequently no corrections for mean monthly solar radiation was made. Total solar radiation has a strong seasonal signal at mid-latitudes. Phytoplankton at mid-latitudes show a strong relationship to solar radiation (Perry *et al.* 1989) and therefore measurement of primary productivity during periods of cloud cover (below average daily solar radiation) will cause a reduction in primary productivity.

The distribution of phytoplankton biomass and productivity off the west coast of Vancouver Island varied considerably in the cross-shelf gradient (E-W direction). During the two study years, phytoplankton biomass showed a 13-fold variability, ranging between 17.3 and 227 mg chl m^{-2}. The surface biomass in the shelf region, ranged from 1.48 -13.4 mg chl m^{-3} while in the beyond shelf region, chlorophyll ranged between 0.17-6.35 mg chl m^{-3}. Similarly, primary productivity varied considerably, ranging from 0.3-26.1 g C m^{-2} d^{-1}. Biomass and productivity were generally higher in the shelf region, with the exception of Brooks Peninsula. It is important to note that in regions of generally high productivity, low rates are also measured, highlighting the variability in the region. Primary productivity variability was greater in the shelf region than the beyond shelf region.

In addition to cross-shelf patchiness, the distribution of phytoplankton biomass and productivity in the long shore directions (N/S) was patchy and varied considerably. The location along Vancouver Island (i.e. La Pérouse Bank, Barkley Canyon, Estevan Point and Brooks Peninsula) where biomass was the highest varied during each cruise. At least once during the two year study period, the highest biomass was measured at each of the four transects. A weak trend of higher biomass at the northern end of Vancouver Island was observed for both the shelf and the beyond shelf regions. The high variability in the cross-shelf and alongshore directions suggests a wide range of environmental conditions exist off the west coast of Vancouver Island. It is likely that the alongshore and the cross-shelf currents play an important role in maintaining the patchy distribution of biomass and productivity.

The distribution of phytoplankton biomass and productivity showed considerable variation in time. In April 1997, we had the opportunity to resample 4 stations within one week. During the second week, the chlorophyll biomass was often higher and NO_3^- was lower than the previous week. During the second week, nutrient depletion of the surface water was also evident to greater depths. No opportunity was available to resample on a shorter time scale. Seasonal variability was observed for biomass and productivity, but the seasonal patterns were not similar in 1997 and 1998. The seasonal peak was seen in April 1997 and in July 1998 for both biomass and primary productivity. Over the two year study period, the highest biomass and primary productivity were measured in July 1998. As was noted earlier, the July cruise was during a period of upwelling favorable winds. The July cruise was the only cruise during the study period that occurred during upwelling favorable conditions. The intensity of upwelling was higher in 1998 than 1997 (R. Thomson, pers. comm.) which may explain high biomass and productivity in July 1998. In July 1998, the phytoplankton community was composed of *Pseud-nitzschia delicatissima*, *Chaetoceros debilis*, *Skeletonema costatum*, *Asterionella glacialis*, and *Dactyliosolen fragillissimus,* but was it dominated by *Chaetoceros* spp. and *Leptocylindrus danicus*. Generally coastal environments are characterized by episodic pulses in biomass caused by chain forming diatoms and occasionally dinoflagellates (Malone, 1980). The phytoplankton assemblage off the west coast of Vancouver Island was consistent with this generalization. The high supply of nutrients during the spring/summer when solar radiation was high was responsible for the persistently high biomass and primary productivity that are characteristic of this upwelling region. Lower productivity measured during October of 1997 and 1998 was likely due to light limitation. Results from chapter one show light availability was lower during October relative to July and April. Nitrate concentrations were surprisingly low in October, with on average concentrations of 3.7 μM in 1997 and 4.7 μM in October 1998. Therefore, nutrient limitation can not account for the low October productivity rates. Variability was generally the highest during July (high

C.V. relative to other cruises.) It is likely that the variance is due to the intermittent nature of upwelling during the summer.

This thesis has shown the importance and substantial contribution of the >5 μm phytoplankton to biomass and primary productivity. The relative contribution of the >5 μm sized phytoplankton tended to increase as biomass and primary productivity increased. For example, during July 1998 when high biomass and productivity was measured, 73% of the phytoplankton community was composed of diatoms, mainly *Chaetoceros* spp. and *Leptocylindrus danicus*. We have also shown that in order to obtain high biomass and primary productivity large cells are required. This is consistent with modeling results obtained by Tremblay and Legendre (1994).

The dynamics of phytoplankton biomass and primary productivity of shelf and beyond shelf regions were distinct in regard to community size structure and seasonality. The shelf regions tend to be dominated by >5 μm sized phytoplankton while the beyond shelf region was dominated by the <5 μm fraction, mainly various flagellates. This is consistent with previous observations that large phytoplankton cells tend to dominate in nutrient-rich coastal waters while small cells are characteristic of nutrient-poor waters (Malone, 1971). Primary productivity in the shelf region was higher than primary productivity in the beyond shelf region. The higher rates measured in the shelf region were due to >5 μm sized phytoplankton since the rates measured for the <5 μm fraction were similar in both regions. Beyond shelf regions are generally characterized by the dominance of the smaller fraction as shown in Figure 2.14 where beyond shelf stations are generally clustered in the bottom left hand corner of the plot. Frequently, the beyond shelf region of Brooks Peninsula showed characteristics more similar to the shelf region. This is not surprising considering the narrow width of the shelf at

Brooks Peninsula. There is a high probability that freshly upwelled water and biomass can quickly be transported beyond the 200 m contour. In addition, wind-driven upwelling filaments (jets) recurrently develop off Brooks Peninsula, and transport a substantial proportion of nutrients, phytoplankton and zooplankton biomass from the shelf to the deep ocean (Forbes *et al.* 1991).

Comparison with previous studies off the west coast of Vancouver Island

Previous studies off the west coast of Vancouver Island by Denman *et al.* (1981) have focused on the southern margin of Vancouver Island. Their region of study overlaps with my measurements on the La Pérouse Bank and Barkley Canyon. Denman *et al.* (1981) found 2 persistent areas of high biomass and high productivity located parallel to the coast, one near the outer edge of the shelf region and the other <20 km offshore. During July 1998, this study found two regions of high biomass that closely match the area described by Denman *et al.* (1981). On average (mean of maximum values for the three cruises), the maximum biomass and productivity found by Denman *et al.* (1981) were higher than those reported in this thesis. Their maximum biomass reached 38.5 mg chl m^{-3}, while the maximum measured during this thesis was 20.4 mg m^{-3}. Lower measurements of biomass is reasonable considering Venrick *et al.* (1987) has shown chlorophyll was higher and sea surface temperature was lower in the early 1980's, the period of Denman *et al.*'s (1981) study, compared to the early 1970's. Considering that above average sea surface temperatures were observed during the 1990's, leads one to hypothesis that chlorophyll levels would be lower in the 1990's compared to the 1980's. Denman *et al.* (1981) also found that on average maximum productivity reached 82 mg C m^{-3} h^{-1} whereas in this study on average, the maximum was 40.4 mg C m^{-3} h^{-1}. The carbon assimilation numbers that were reported by Denman *et al.* (1981) were similar.

The primary productivity rates measured in this study are similar to those found by Whitney *et al.* (1999). They reported primary productivity values of 2.4 g C m^{-2} d^{-1}, which is lower than values found in this thesis, but considering the more offshore nature of their station (P4) relative to the regions in this thesis, lower values for their station would be expected.

The high spatial and temporal heterogeneity is in close agreement with Boyd *et al.*, (1999). Boyd *et al.* (1999) reported marked seasonal and interannual variability of phytoplankton biomass and primary productivity at an offshore P4 station (depth 1300 m). The present study found beyond shelf regions were dominated by <5 μm sized phytoplankton which is similar to the community structure found by Boyd *et al.* (1999).

A general cross-shelf gradient in phytoplankton biomass has been reported by Mackas, (1992) and Perry *et al.* (1999). Generally, the shelf region was characterized by higher chlorophyll concentrations than beyond the shelf region. Mackas (1992) found that for zooplankton biomass the outer shelf had the least seasonal variability, which is similar to the low variability I found for chlorophyll and primary productivity in the beyond shelf region.

The elevated biomass and primary productivity and the carbon assimilation rates for the beyond shelf region off Brooks Peninsula are consistent with results by Forbes *et al.* (1986).

A comparison of size-fractionated biomass and primary productivity with previous studies in the area is not possible since this is the first study to examine size-fractionated biomass and primary productivity. However, a comparison with results of a one-dimensional simulation model of plankton and fish production was made. Robinson and Ware (1999) found annual diatom production was lower in 1997 than 1998 which agrees with observations from this study that the >5 μm biomass and productivity were lower in 1997 than in 1998 and the relative contribution to biomass by the large fraction was lower in 1997. Primary productivity for the southern margin was 3.5 mg C m^{-2} d^{-1} in 1997, lower than 4.0 mg C m^{-2} d^{-1} in 1998. The results of this study agree well with model simulation results. Robinson and Ware (1998) found diatom production has steadily declined since the mid-1980s, largely due to a decrease in upwelling intensity. This observation may help explain lower biomass and primary productivity in this study compared to values found by Denman *et al.* (1981).

Comparison with other upwelling regions

Phytoplankton dynamics found for coastal upwelling regions off Washington are similar to results obtained in this thesis off the west coast of Vancouver Island. Coastal Zone Color Scanner images off the Washington coast showed patchy distribution of biomass and features such as jets were common (Perry *et al.* 1989). High phytoplankton biomass and primary productivity in the coastal upwelling areas off Washington were reported by Perry *et al.* (1989). In the shelf region, biomass ranged from 1-11.0 mg chl m^{-3}, while the range for the beyond shelf region was 0.3-8.5 mg chl m^{-3}. Perry *et al.* (1981) found a general cross-shelf gradient in biomass and productivity, which agrees with the results of this study. Generally, the primary productivity off Washington was 4 g C m^{-2} d^{-1} in the shelf region, higher than 1.5 g C m^{-2} d^{-1} in the beyond shelf region. These rates are close to those found in this study, which was 5.1 g C m^{-2} d^{-1} in the shelf region and 2.0 g C m^{-2} d^{-1} in the beyond shelf region. Generally, primary productivity off the coast of Washington was highest in the spring, but Perry *et al.* (1989) also found equally high rates in the summer. This is consistent with the results of this study that found the highest primary productivity in the spring of 1997 and in the summer of 1998.

Phytoplankton biomass and primary productivity was on average higher off the west coast of Vancouver Island than found for Monterey Bay, CA. (Wilkerson *et al.* 1999), but the results of this study agree closely with the relative contribution by the >5 μm size fraction reported by Wilkerson *et al.* (1999). Wilkerson *et al.* (1999) found that the larger sized phytoplankton (>5 μm fraction) contributed significantly to biomass and productivity in

Monterey Bay. On average, the >5 μm fraction accounted for 50% of the total chlorophyll and 56% of the primary productivity (Wilkerson *et al.* 1999) compared to 49% of total chlorophyll and 57% of primary productivity found off the west coast of Vancouver Island.

SUMMARY

Primary productivity and biomass were high off the west coast of Vancouver Island. The >5 μm phytoplankton contributed significantly to biomass and primary productivity off the west coast of Vancouver Island and the relative contribution of the >5 μm cells increased as the phytoplankton biomass or productivity increased. This study has shown that high phytoplankton biomass and primary productivity develop due to the presence of large cells, which were predominately diatoms.

Phytoplankton in the beyond shelf region tended to be dominated by the <5 μm size fraction. while in the shelf region the >5 μm size fraction dominated. The phytoplankton assemblage in the beyond shelf region was composed of various flagellates, while diatoms dominated by *Chaetoceros* spp. and *Leptocylindrus danicus,* were common in the shelf region. On average, the relative contribution of the >5 μm size to total chlorophyll was 62% in the shelf region compared to 29% in the beyond shelf region. Similarly, the relative contribution of the >5 μm size fraction to primary productivity was 72% in the shelf region, while only 36% in the beyond shelf region. Clearly, the size structure of biomass and primary productivity were different for the shelf and the beyond shelf regions.

GENERAL DISCUSSION

This study was conducted during an extreme ENSO event. One of the strongest ever recorded El Niño event occurred during 1997/98, the first year of this sampling program. Conversely, a strong La Niña event was recorded during 1998/99, the second year of this sampling program. The 1997/98 El Niño event peaked in February 1998 and ended abruptly in May of 1998 but sea surface temperatures in the coastal regions remained slightly higher than average until December 1998 (Freeland, 1998). The April 1997 cruise occurred before temperature anomalies were observed off the west coat of Vancouver Island, while the July and October 1997 cruises occurred during the 1997/98 El Niño event. The May, July and October 1998 cruises occurred during the 1998-99 La Niña event. One would expect interannual variability in the ocean climate given the magnitude of this most recent climatic oscillation. This study has shown the mixed layer was shallower and less saline in 1997. This suggests that the level of upwelling was lower in 1997 than 1998. Examination of a 30 year record of upwelling intensity revealed that the lowest index of upwelling occurred during 1997 (I. Perry, pers. comm.). Despite lower upwelling in 1997 relative to 1998, nitrate and silicic acid concentrations were higher in 1997, the year of less intense upwelling. Nutrient concentration is a non-conservative tracer and is influenced by the biological community. Lower nutrient concentrations in 1998 are not surprising considering phytoplankton biomass, particularly diatom biomass was higher in 1998 which would allow for rapid depletion of the nutrient pools. In fact, nitrate concentrations near or at detection limits were frequently measured. Lower nutrient concentrations observed in this study agree with Whitney *et al.* (1998) who found that nitrate during 1998 was lower than the 1969-1981 average nitrate concentration.

The dominant time scale of variability off the west coast of the biology and physics such as ocean currents, is the annual cycle (Denman *et al.* 1989). On a shorter time scale, current flucuatations have time scales of the order of 10 days and winds events occur on the order of days. Turnover times for phytoplankton are typically days therefore during the course of each cruise the phytoplankton are exposed to flucuating physical conditions. The arrival time at stations during the cruises was random, therefore the chance to arrival at at station before or after a wind event is equal. Denman *et al.* (1989) suggest that if data was collected frequently enough, on the order of days to weeks, interannual and interdecadal anomalies can be clearly shown. The 1997 annual mean averaged results for 2 cruises during the El Niño while the 1998 annual mean averages results for 3 cruises during the La Niña. Given the random arrival time at the stations, the near equal time scale for biological and physical events and the equal distribution of cruises between El Niño and La Niña events the annual means presented in this study are valid.

This study has also shown that the shelf and beyond shelf regions showed distinct physical, chemical and biological parameters. Temperature, salinity, density, chlorophyll, phytoplankton abundance, total phytoplankton biomass and diatom biomass all showed a strong cross-shelf gradient. Generally, the shelf region tended to be more productive than the beyond shelf region. The cross-shelf gradient is influenced by the Vancouver Island Coastal Current, which acts as a barrier to exchange between the shelf and the beyond shelf regions (Thomson *et al.* 1989). Thomson *et al.* (1989) also suggested that the current might act as a conduit for alongshore transport. This study did not find a consistent pattern of long shore distribution of nutrients, biomass or productivity. This does not exclude the possibility that a latitudinal gradient exists or that the VICC does not influence the distribution of chemical and biological parameters. Although this study was extensive both in time and space, the cruises were only for 2-3 weeks, three times per year and only provided a snapshot of conditions. Satellite images could expand the time series and fill in gaps between cruises. The VICC is a physical feature that acts as a barrier to exchange across the shelf break, while spatially localized jet-like currents that transport shelf water offshore act as a conduit for exchange Denman *et al.* (1989). This study found evidence of this at the Brooks Peninsula transect, since biomass and productivity in the beyond shelf region were frequently similar to that found in the shelf region.

This study has shown the substantial contribution that the >5 μm sized phytoplankton make to biomass and productivity off the west coast of Vancouver Island. The relative importance was higher in the shelf region as was the abundance of diatoms. This study has shown that large cells (>5 μm) are largely composed of diatoms. Frequently, *Chaetoceros* spp. and *Leptocylindrus danicus* dominated the assemblage when high chlorophyll concentrations and high primary productivity were measured. In the beyond shelf region, various flagellates dominated the assemblage, resulting in a lower contribution of >5 μm phytoplankton. In addition, high biomass and productivity were measured when the assemblage was dominated by large cells, not small cells. This implies that in order to obtain high biomass or productivity, large cells must be present. The dominance of large cells has important ramifications for the local food chain. Larger cells tend to support a shorter food chain leading to more efficient transfer of energy to upper trophic levels (Ryther, 1969). The dominance of large cells perhaps explains why the La Pérouse Bank has historically supported a diverse and highly productive fishery (Ware and Thomson, 1991). The size structure of the phytoplankton community has important implications for the downward flux to sediments, since the magnitude of the downward flux is dependent on the assemblage structure (Michaels and Silver, 1988). It is more likely that larger phytoplankton will contribute more significantly to the vertical flux than smaller sized phytoplankton. This study has shown that there is variability in the size structure of the phytoplankton community that must be considered in modeling efforts.

This study described the physical, chemical, and biological characteristics of four transects off the west coast of Vancouver Island. This was the first study to investigate: 1) size-fractionated biomass and rates of size-fractionated primary production along transects off the west coast of Vancouver Island; b) phytoplankton species composition from the southern to the northern margin of Vancouver Island; and c) the relative contribution of small and large cells to biomass and primary productivity off the west coast of Vancouver Island.

FUTURE RESEARCH

The results of this study have suggested additional studies that warrant further examination. Suggestions for future research include:

a) Further studies on size-fractionated biomass and productivity in the beyond shelf region to determination the relative contribution of picoplankton, particularly during periods of surface nutrient depletion. The beyond shelf region had low biomass, low nutrients and was dominated by the <5 μm size fraction and it is likely that small picoplankton cells which have favorable nutrient uptake rates, contributed to the biomass and productivity. The relative contribution of picoplankton in the shelf region is likely to be much less important. The shelf region is generally nutrient rich and therefore the competitive advantage of the small cells would be outweighed by diatoms rapid nutrient uptake rates.

b) Compare rates of nitrogen uptake to rates of primary productivity to examine if uptake rates approach Redfield ratios.

c) Examine primary productivity in an upwelling jet to determine physiological changes that occur as water is advected offshore. Does the sequence of changes conform to the "conveyor belt" proposed by Dugdale and Wilkerson (1985)?

d) Determination of primary productivity on the shelf break. High biomass is often found at the frontal edge between the shelf and the beyond shelf region.

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APPENDIX A

CRUISE DETAILS

Table A.1 Cruise dates and season for 3 cruises during 1997, 1998 and 1999. Transition date is the date the prevailing wind shifted for the season and it was calculated using Thomson & Ware's wind velocity index (R. Thomson pers. comm.). Seasonal classification is based on the prevailing winds. (-) denotes information is not available.

Cruise I.D.	Date	Season	Transition Date	Northwesterly Winds
1997 Cruises				
9707	07 - 14 April	Spring	Jan. 30	No
9707	21 - 28 April	Spring	Jan. 30	No
9713	14 - 28 July	Fall	May 16	No
9737	20 - 27 Oct.	Fall	June 12	No
1998 Cruises				
9810	11 - 25 May	Spring/Summer	Feb. 25	Yes
9823	13 - 27 July	Summer	May 7	Yes
9836	05 - 13 Oct.	Fall	Oct. 23	No
1999 Cruises				
9911	04-12 May	Spring	Jan 30	No
9928	30 June-06 July	Summer	02 June	Yes
9935	23-30 Sept.	Fall	30 Aug.	No

APPENDIX B

1999 DISSOLVED NUTRIENT RAW DATA SET

Table B.1 NO_3^-, HPO_4^- and $Si(OH)_4$ in May 1999 off the west coast of Vancouver Island. Dashed line (-) indicates that data point is not available. (-) indicates information is not available; b-10 indicates water sample was collected at 10 m off the bottom.

Station	Date	Cast #	Niskin #	Depth (m)	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
B2	04-May-99	4	5	0	18.5	1.7	29.9
B2		4	4	10	19.1	1.8	29.3
B2		4	3	20	22.0	2.0	33.0
B2		4	2	30	23.7	2.1	34.6
B2		4	1	50	14.2	1.3	29.4
B4	04-May-99	6	7	0	1.7	0.6	19.3
B4		6	6	10	12.5	1.2	25.3
B4		6	5	20	12.6	1.3	25.8
B4		6	4	30	10.2	0.8	19.6
B4		6	3	50	19.5	1.3	27.8
B4		6	2	75	13.2	0.9	22.1
B4		6	1	100	32.9	2.6	50.2
B6	05-May-99	8	7	0	0.0	0.4	12.9
B6		8	6	10	1.9	0.0	7.9
B6		8	5	20	11.1	1.1	20.4
B6		8	4	30	8.0	0.5	14.1
B6		8	3	50	16.2	1.5	29.1
B6		8	2	75	12.4	1.0	22.1
B6		8	1	100	25.1	2.2	44.8
B8	05-May-99	14	4	50	15.6	1.5	23.7
B8		14	3	75	16.9	1.4	24.3
B8		14	2	100	22.0	1.8	60.7
B8		14	1	130	33.9	3.0	82.1
B10	06-May-99	46	9	0	0.4	0.4	12.7
B10		46	8	10	0.5	0.4	11.4
B10		46	7	20	4.7	0.8	14.9
B10		46	6	30	4.8	0.6	13.9
B10		46	5	50	5.3	0.5	12.7
B10		46	4	75	7.6	0.5	13.5
B10		46	3	100	23.1	2.0	30.9
B10		46	2	125	33.6	2.6	47.5
B12	06-May-99	44	11	50	4.8	0.3	9.8
B12		44	10	75	10.0	1.2	15.3
B12		44	9	100	24.1	2.1	29.7
B12		44	8	125	28.7	2.4	37.0
B12		44	7	150	33.2	2.4	41.3
B12		44	6	175	35.2	2.7	47.0
B12		44	5	200	17.2	1.4	29.8
B12		44	4	250	36.9	2.8	54.1
B12		44	3	300	35.8	2.6	58.1
B12		44	2	400	36.8	2.7	55.2
B12		44	1	495	28.2	2.0	37.6
B16	06-May-99	43	8	40	8.1	1.1	15.5
B16		43	7	50	4.6	0.3	10.9
B16		43	6	75	12.0	1.3	29.9
B16		43	5	100	30.4	2.4	82.0
B16		43	4	125	32.1	2.5	80.1
B16		43	3	150	27.0	2.1	78.0
B16		43	2	175	34.4	2.6	83.2
B16		43	1	200	35.8	2.7	47.7

APPENDIX B

Table B.1 continued. Dissolved nutrients in May 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
B16	05-May-99	42	-	500	32.2	2.6	51.0
B16		42	-	600	52.9	4.0	72.2
B16		42	-	700	46.7	3.7	47.7
B16		42	-	800	46.8	3.7	48.5
B16		42	-	1000	25.9	2.2	37.9
B16		42	-	1200	46.5	3.7	49.7
B16		42	-	1500	46.3	3.6	59.6
B16		42	-	1669	22.9	1.7	54.9
B16		42	-	1778	45.6	3.5	75.0
C1	05-May-99	9	8	15	6.6	0.6	23.7
C1		9	7	20	16.3	1.6	32.2
C1		9	6	30	19.6	2.0	33.6
C1		9	5	50	18.0	1.7	32.8
C1		9	4	75	15.8	1.6	26.6
C1		9	3	100	30.1	2.8	52.6
C1		9	2	125	29.1	2.4	58.7
C1		9	1	b-10	33.0	2.9	68.1
C2	05-May-99	21	7	0	2.9	0.5	6.5
C2		21	6	10	0.7	0.0	3.4
C2		21	5	20	3.3	0.3	6.8
C2		21	4	30	13.1	1.5	20.3
C2		21	3	50	11.4	1.0	19.1
C2		21	2	75	12.6	1.0	20.1
C2		21	1	100	12.1	0.7	21.7
C4	05-May-99	23	7	20	6.8	0.9	12.1
C4		23	6	31	13.5	1.5	23.5
C4		23	5	50	16.0	1.6	23.0
C4		23	4	75	16.1	1.6	21.8
C4		23	3	100	21.0	1.8	24.8
C4		23	2	125	18.4	1.8	26.1
C4		23	1	154	18.5	1.7	25.9
C7	05-May-99	27	6	20	1.2	0.1	8.7
C7		27	5	30	8.3	1.1	15.1
C7		27	4	50	7.6	0.8	11.3
C7		27	3	75	11.8	1.4	15.7
C7		27	2	100	20.8	2.3	35.3
C7		27	1	120	28.7	2.8	49.5
C8	05-May-99	28	8	50	5.0	0.6	10.1
C8		28	7	75	10.9	1.3	14.9
C8		28	5	100	11.6	0.9	17.0
C8		28	4	125	27.2	2.1	28.0
C8		28	3	150	33.4	2.4	37.7
C8		28	2	175	37.6	2.9	51.3
C8		28	1	190	38.1	3.0	54.3
C9	05-May-99	30	13	25	5.0	0.9	15.7
C9		30	12	30	4.1	0.4	14.4
C9		30	11	50	10.6	1.2	54.1
C9		30	10	75	24.3	2.1	63.6
C9		30	9	100	16.4	1.3	52.1
C9		30	8	125	33.5	2.4	64.5
C9		30	7	150	25.4	1.6	55.2
C9		30	6	175	35.4	2.7	89.2
C9		30	5	200	37.6	2.8	48.6
C9		30	4	250	30.9	2.3	43.8
C9		30	3	300	31.1	2.0	46.5
C9		30	2	400	32.1	2.4	44.6
C9		30	1	500	44.6	3.4	55.9
C11	05-May-99	36	13	75	17.2	1.6	22.5
C11		36	12	100	25.6	2.0	37.7
C11		36	11	125	22.9	1.8	37.5
C11		36	10	150	23.7	1.8	39.2
C11		36	9	176	34.4	2.6	48.3
C11		36	8	200	35.8	2.8	52.2

APPENDIX B

Table B.1 continued. Dissolved nutrients in May 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
C11	05-May-99	36	7	300	39.4	3.0	57.0
C11		36	6	400	27.8	1.9	46.4
C11		36	5	500	26.5	1.9	37.8
C11		36	4	750	45.4	3.6	48.0
C11		36	3	1000	43.8	3.6	89.4
C11		36	2	1250	45.3	3.6	81.7
C11		36	1	1445	45.3	3.6	98.7
C14	06-May-99	40	-	0	1.1	0.6	12.1
C14		40	-	10	1.1	0.6	11.4
C14		40	-	20	1.1	0.5	10.5
C14		40	-	30	5.9	1.0	13.5
C14		40	-	50	8.5	1.0	13.6
C14		40	-	75	15.3	1.3	19.3
C14		40	-	100	16.0	0.9	21.6
C14		40	-	120	30.7	2.3	37.8
C14		40	-	150	31.5	2.4	40.7
C14		40	-	175	35.0	2.5	45.2
C14		40	-	200	34.0	2.6	48.2
C14		40		250	29.1	2.2	51.7
C14		40	-	300	18.1	1.6	37.1
C14		40	-	400	40.4	3.1	48.9
C14		40	-	500	25.7	2.0	36.0
C14		40	-	750	42.2	3.6	51.9
C14		40	-	1000	38.6	3.3	51.8
C14		40	-	b-10	37.2	3.1	58.8
D4	06-May-99	50	7	0	5.5	0.7	11.0
D4		50	6	10	9.4	0.9	16.0
D4		50	4	30	10.7	1.3	16.3
D4		50	3	40	7.8	0.5	13.7
D4		50	2	50	15.2	1.6	22.9
G1	07-May-99	52	5	0	0.4	0.0	4.3
G1		52	4	10	3.0	0.5	9.2
G1		52	3	20	3.1	0.7	9.0
G1		52	2	30	3.5	0.7	9.2
G1		52	1	50	3.4	0.4	10.3
G2	07-May-99	52	7	0	0.4	0.1	7.4
G2		52	6	10	0.5	0.0	5.2
G2		52	5	20	2.5	0.6	8.0
G2		52	4	30	7.7	1.0	15.4
G2		52	3	50	5.2	0.3	12.0
G2		52	2	75	14.2	1.4	20.1
G2		52	1	100	18.4	1.4	31.8
G3	07-May-99	65	8	15	2.1	0.6	14.3
G3		65	7	20	1.6	0.1	13.0
G3		65	6	30	3.9	0.4	10.7
G3		65	5	40	4.9	0.4	10.3
G3		65	4	50	11.1	1.3	14.3
G3		65	3	75	9.7	0.6	38.2
G3		65	2	100	31.5	2.4	80.3
G3		65	1	b-10	25.2	1.8	72.1
G4	07-May-99	56	6	30	26.1	2.1	34.5
G4		56	5	50	18.8	1.7	26.2
G4		56	3	100	27.7	2.0	35.0
G4		56	2	125	24.8	1.3	39.3
G4		56	1	141	25.2	1.5	40.8
G7	06-May-99	59	12	30	3.1	0.7	12.6
G7		59	11	40	6.6	1.0	14.2
G7		59	10	50	8.0	1.1	16.8
G7		59	9	75	8.5	0.9	47.3
G7		59	8	100	17.0	1.5	30.5
G7		59	7	125	28.9	2.2	37.8
G7		59	6	175	24.3	1.9	43.2
G7		59	5	200	34.8	2.7	49.0

APPENDIX B

Table B.1 continued. Dissolved nutrients in May 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
G7	06-May-99	59	4	250	25.8	1.6	50.4
G7		59	3	300	40.4	3.1	63.1
G7		59	2	400	27.2	1.6	55.7
G7		59	1	500	45.1	3.5	72.0
G7		63	12	500	35.9	2.5	43.6
G7		63	11	600	50.4	3.9	75.7
G7		63	9	800	32.1	2.5	57.3
G7		63	7	1000	51.8	4.0	137.7
G9	07-May-99	64	16	0	0.8	0.6	10.3
G9		64	15	10	0.5	0.6	9.2
G9		64	14	20	0.2	0.0	6.4
G9		64	13	30	1.1	0.1	7.1
G9		64	12	50	7.7	1.1	14.5
G9		64	11	75	14.2	1.4	18.9
G9		64	10	100	19.7	1.3	30.6
G9		64	9	125	22.2	1.6	35.1
G9		64	8	150	19.1	1.3	32.9
G9		64	7	175	32.7	2.5	48.7
G9		64	6	200	13.2	0.7	22.9
G9		64	5	300	28.5	2.0	55.6
G9		64	4	400	45.1	3.3	51.7
G9		64	3	500	26.0	2.0	39.4
G9		64	2	750	46.7	3.5	86.9
G9		64	1	1000	38.6	3.0	104.7
J2	11-May-99	125	6	0	0.7	0.1	-
J2		125	5	10	0.9	0.1	-
J2		125	4	20	2.4	0.2	-
J2		125	3	30	5.7	0.3	-
J2		125	2	50	10.8	0.4	-
J2		125	1	56	13.8	0.5	-
J3	11-May-99	-	6	0	0.6	0.8	2.3
J3		-	5	10	0.6	0.8	2.3
J3		-	4	20	2.9	0.7	2.3
J3		-	3	30	5.4	1.4	4.2
J3		-	2	50	8.2	1.6	9.3
J3		-	1	72	8.8	1.5	8.6
J4	11-May-99	128	5	50	13.4	1.5	22.6
J4		128	4	75	22.1	2.1	34.8
J4		128	3	100	22.4	1.6	36.5
J4		128	2	125	36.9	2.8	49.2
J4		128	1	150	34.8	2.4	41.6
J8	11-May-99	134	17	0	0.5	0.4	2.3
J8		134	16	10	0.3	0.7	2.3
J8		134	15	20	1.4	1.0	2.3
J8		134	14	30	2.6	1.1	2.5
J8		134	13	50	6.3	1.3	4.1
J8		134	12	75	10.7	1.6	7.6
J8		134	11	100	14.1	1.0	25.3
J8		134	10	125	30.5	2.5	44.6
J8		134	9	150	33.6	2.6	47.1
J8		134	8	175	34.9	2.6	50.2
J8		134	7	200	37.6	2.8	55.0
J8		134	6	300	30.7	2.2	50.0
J8		134	5	400	23.8	1.6	42.1
J8		134	4	500	29.5	2.1	44.1
J8		134	3	600	45.3	3.4	58.7
J8		134	2	800	41.6	3.2	66.0
J8		134	1	1000	43.6	3.8	144.5
J6	11-May-99	131	17	20	0.5	0.5	2.3
J6		131	16	30	0.6	0.6	2.3
J6		131	15	50	1.2	0.4	2.3
J6		131	14	75	1.3	0.3	2.3
J6		131	13	100	3.4	0.7	2.3

Table B.1 continued. Dissolved nutrients in May 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- μM	HPO_4^{2-} μM	$Si(OH)_4$ μM
J6	11-May-99	131	12	125	12.9	1.3	9.4
J6		131	11	150	18.0	1.2	28.1
J6		131	10	175	20.0	1.6	29.7
J6		131	9	200	30.1	2.4	39.9
J6		131	8	250	35.6	2.7	38.9
J6		131	7	300	18.7	1.3	28.7
J6		131	6	400	38.3	2.6	31.3
J6		131	5	500	43.6	3.3	54.7
J6		131	4	600	45.6	3.5	44.2
J6		131	3	800	22.0	1.7	25.9
J6		131	2	1000	32.1	2.5	35.2
J6		131	1	1099	28.7	2.0	26.2
BP4	10-May-99	117	17	0	1.1	0.1	-
BP4		117	16	10	2.1	0.2	-
BP4		117	15	20	2.0	0.1	-
BP4		117	14	30	3.4	0.1	-
BP4		117	13	50	6.6	0.3	-
BP4		117	12	75	6.9	0.2	-
BP4		117	11	100	5.5	0.9	11.0
BP4		117	10	125	32.6	2.5	41.1
BP4		117	9	150	35.3	2.7	46.0
BP4		117	8	175	36.2	2.7	46.8
BP4		117	7	200	38.4	2.8	50.6
BP4		117	6	300	39.9	3.1	52.0
BP4		117	5	400	42.0	3.3	43.2
BP4		117	4	500	18.9	1.5	23.7
BP4		117	3	750	45.1	3.6	44.4
BP4		117	2	800	45.6	3.6	48.1
BP4		117	1	910	24.9	2.0	36.2
BP7	10-May-99	123	16	0	2.8	0.1	-
BP7		123	15	5	2.7	0.0	-
BP7		123	14	10	3.7	0.2	-
BP7		123	13	20	3.9	0.3	-
BP7		123	12	30	6.8	0.3	-
BP7		123	11	50	7.0	0.3	-
BP7		123	10	75	10.6	0.4	-
BP7		123	9	100	12.3	1.5	17.5
BP7		123	8	125	25.1	2.3	34.0
BP7		123	7	150	27.2	2.4	39.3
BP7		123	6	175	28.1	2.4	42.8
BP7		123	5	200	29.9	2.5	48.4
BP7		123	4	250	42.5	3.8	32.9
BP7		123	3	300	35.8	2.9	64.1
BP7		123	2	400	39.3	3.2	54.0
BP7		123	1	500	42.7	3.5	56.0
BP8	10-May-99	110	21	0	0.7	0.5	8.8
BP8		110	20	10	1.1	0.6	9.4
BP8		110	19	20	1.8	0.6	9.3
BP8		110	18	30	3.4	0.7	10.0
BP8		110	17	50	6.9	0.7	17.3
BP8		110	16	75	12.3	1.3	18.7
BP8		110	15	100	8.3	0.5	14.8
BP8		110	14	125	21.7	1.9	29.1
BP8		110	13	150	21.5	1.6	35.7
BP8		110	12	175	21.4	1.6	36.7
BP8		110	11	200	32.7	2.6	46.8
BP8		110	10	250	34.0	2.7	53.9
BP8		110	9	300	36.9	2.9	61.2
BP8		110	8	400	40.7	3.2	66.0
BP8		110	7	500	45.2	3.3	76.7
BP8		110	6	600	46.6	3.5	66.0

APPENDIX B

Table B.1 continued. Dissolved nutrients in May 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
BP8	10-May-99	110	5	800	24.7	2.0	37.7
BP8		110	4	1000	47.1	3.6	71.9
BP8		110	3	1200	47.3	3.5	64.1
BP8		110	2	1500	42.2	3.2	51.6
BP8		110	1	2000	44.6	3.4	60.1
MP8	11-May-99	137	17	0	2.9	1.1	2.3
MP8		137	16	10	1.5	0.5	2.3
MP8		137	15	20	3.9	1.2	3.0
MP8		137	14	30	5.2	0.8	2.8
MP8		137	13	50	10.1	1.6	2.3
MP8		137	12	75	8.9	1.1	2.3
MP8		137	11	100	24.7	2.2	71.8
MP8		137	10	125	23.0	1.8	65.6
MP8		137	9	150	21.5	1.8	60.0
MP8		137	8	175	27.7	2.0	58.7
MP8		137	7	200	33.1	2.3	46.2
MP8		137	6	300	26.8	2.0	44.2
MP8		137	5	400	20.2	1.3	25.3
MP8		137	4	500	47.5	3.5	48.7
MP8		137	3	600	38.3	3.4	46.3
MP8		137	2	800	23.9	2.3	29.2
MP8		137	1	1000	26.9	2.4	34.1
CPE2	09-May-99	107	8	0	0.1	0.4	4.7
CPE2		107	7	10	0.3	0.3	7.5
CPE2		107	6	20	2.3	1.0	8.6
CPE2		107	5	30	2.9	0.4	5.9
CPE2		107	4	50	4.4	1.2	12.3
CPE2		107	3	75	8.1	0.8	16.7
CPE2		107	2	100	23.7	2.0	31.1
CPE2		107	1	117	44.7	3.4	58.3
CS3B	09-May-99	95	11	0	5.5	0.6	12.0
CS3B		95	10	10	2.6	0.0	7.6
CS3B		95	9	20	6.7	0.8	12.5
CS3B		95	8	30	7.0	0.7	12.9
CS3B		95	7	50	5.3	0.3	13.1
CS3B		95	6	75	8.7	1.0	16.0
CS3B		95	5	100	11.1	1.1	17.3
CS3B		95	4	125	10.5	1.1	16.5
CS3B		95	3	150	18.6	1.6	25.4
CS3B		95	1	175	19.5	1.3	33.7
CS3B		95	1	221	35.5	2.7	55.8
CS1	08-May-99	67	10	50	8.2	1.1	14.9
CS1		67	9	75	6.8	0.6	13.0
CS1		67	8	100	18.2	1.8	60.5
CS1		67	7	125	25.1	2.2	71.3
CS1		67	6	150	30.4	2.6	80.8
CS1		67	5	175	17.9	1.2	69.4
CS1		67	4	200	32.4	2.6	84.2
CS1		67	3	300	36.4	3.0	93.2
CS1		67	2	400	29.9	2.5	83.4
CS1		67	1	500	29.8	2.0	70.1
CS3	08-May-99	73	11	0	2.6	0.9	2.3
CS3		73	10	10	2.8	1.0	2.3
CS3		73	9	20	4.0	1.0	2.3
CS3		73	8	30	4.0	0.8	2.3
CS3		73	7	50	8.5	1.4	5.7
CS3		73	6	75	9.6	1.5	8.5
CS3		73	5	100	8.3	0.6	58.0
CS3		73	4	120	32.4	2.5	88.0
CS3		73	3	150	30.6	2.7	85.8
CS3		73	2	175	33.9	2.9	89.6
CS3		73	1	200	39.5	3.0	86.6

APPENDIX B

Table B.1 continued. Dissolved nutrients in May 1999

Station	Date	Cast #	Niskin #	Depth (m)	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
CS5	08-May-99	77	3	30	5.6	0.4	12.8
CS5		77	2	50	10.4	1.0	17.4
CS5		77	1	57	8.0	0.5	16.1
CS7	08-May-99	82	6	0	5.6	0.8	13.0
CS7		82	5	10	6.0	0.9	13.5
CS7		82	4	20	4.6	0.4	10.3
CS7		82	3	30	5.6	0.3	12.8
CS7		82	1	56	10.8	1.1	20.5
CS9	08-May-99	88	11	0	3.6	0.9	2.3
CS9		88	9	10	5.3	1.1	2.7
CS9		88	10	20	3.4	0.8	2.3
CS9		88	8	30	5.8	1.1	3.6
CS9		88	7	50	8.8	1.4	2.3
CS9		88	6	75	6.0	0.8	2.3
CS9		88	5	100	10.2	0.9	60.8
CS9		88	4	125	24.7	2.1	35.8
CS9		88	3	150	32.1	2.6	47.9
CS9		88	2	175	37.1	2.9	50.3
CS9		88	1	179	37.7	2.9	53.7

APPENDIX B

1999 DISSOLVED NUTRIENTS RAW DATA SET

Table B.2 NO_3^-, HPO_4^- and $Si(OH)_4$ in July 1999 off the west coast of Vancouver Island. All samples were collected and analyzed as outlined in methods section of Chapter 1. (-) indicates information is not available.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
B6	30-Jun-99	6	9	0	4.6	0.2	8.1
B6		6	8	5	7.1	0.4	9.7
B6		6	7	10	15.7	1.1	16.4
B6		6	6	20	32.5	1.8	53.5
B6		6	5	30	22.5	1.3	44.6
B6		6	4	50	29.5	1.7	49.7
B8	30-Jun-99	8	9	0	2.1	0.5	9.5
B8		8	8	10	19.9	1.2	17.9
B8		8	7	20	15.9	1.4	18.3
B8		8	5	50	28.4	1.6	11.1
B8		8	4	75	22.0	1.7	21.8
B8		8	3	100	24.7	2.2	46.5
B8		8	2	125	34.5	3.0	63.5
B8		8	1	144	20.7	1.8	45.6
B16	1-Jul-99	18	6	20	0.7	0.0	26.1
B16		18	5	25	2.1	0.3	28.5
B16		18	4	30	6.0	0.7	30.8
B16		18	3	45	10.3	0.9	30.5
B16		18	2	55	9.5	0.6	25.2
B16		18	1	100	20.0	1.3	31.3
C1	1-Jul-99	33	7	0	1.7	0.0	6.9
C1		33	6	10	8.5	0.3	13.0
C1		33	5	20	33.8	2.0	37.8
C1		33	4	30	36.3	2.2	42.2
C1		33	3	50	38.5	2.3	44.5
C1		33	2	75	41.5	2.5	46.4
C1		33	1	90	42.1	2.4	70.4
C2	1-Jul-99	34	7	0	3.3	0.6	15.2
C2		34	6	10	14.1	1.2	-
C2		34	5	20	25.0	2.0	29.6
C2		34	4	30	29.9	2.3	34.7
C2		34	3	50	33.0	2.4	42.5
C2		34	2	75	27.6	2.1	40.7
C2		34	1	95	35.4	2.6	46.0
C4	1-Jul-99	36	14	0	12.3	1.1	18.7
C4		36	13	5	4.9	0.3	9.7
C4		36	12	6	12.4	1.1	15.8
C4		36	11	5	13.3	1.2	17.3
C4		36	10	8	11.1	0.9	14.4
C4		36	9	18	32.0	2.3	35.6
C4		36	8	34	22.5	2.0	37.0
C4		36	7	41	12.2	1.2	24.4
C4		36	6	50	26.5	2.4	37.2
C4		36	5	75	26.6	2.4	41.6
C4		36	4	100	20.4	1.9	39.5
C4		36	3	125	27.7	2.5	40.1
C4		36	2	150	21.9	2.1	42.1
C4		36	1	164	28.8	2.7	35.1
C5	2-Jul-99	38	6	0	3.4	0.2	9.3
C5		38	5	10	7.6	0.8	14.8
C5		38	4	20	35.3	2.2	32.7
C5		38	3	30	36.6	2.3	35.0
C5		38	2	50	40.2	2.7	42.0
C5		38	1	60	40.1	2.7	25.5

APPENDIX B

Table B.2 continued. Dissolved nutrients in July 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
C6	2-Jul-99	39	6	10	0.0	0.3	3.6
C6		39	5	20	6.5	0.7	8.1
C6		39	4	30	20.8	1.5	20.0
C6		39	3	50	29.3	1.9	26.3
C6		39	2	75	41.3	2.4	38.1
C6		39	1	86	38.1	2.4	51.4
C7	2-Jul-99	40	8	0	0.0	0.4	5.5
C7		40	7	10	0.2	0.1	4.7
C7		40	6	20	4.7	0.8	12.4
C7		40	5	30	11.0	0.9	13.9
C7		40	4	50	11.5	0.7	12.2
C7		40	3	75	15.5	0.7	13.1
C7		40	2	100	21.7	1.7	32.4
C7		40	1	122	30.1	2.5	42.9
C8	2-Jul-99	41	11	0	1.0	0.0	28.8
C8		41	10	10	0.1	0.5	30.1
C8		41	9	20	4.3	0.3	30.1
C8		41	8	30	10.2	0.7	31.3
C8		41	7	50	35.1	1.8	50.1
C8		41	6	75	45.2	2.6	62.7
C9	2-Jul-99	42	16	0	0.9	0.0	17.1
C9		42	5	250	34.0	2.9	61.4
C9		42	4	300	36.3	3.0	66.8
C9		42	3	400	39.2	3.2	75.7
C9		42	2	400	39.9	3.4	87.7
C9		42	1	612	40.9	3.4	96.6
C11	2-Jul-99	46	20	0	1.6	0.4	5.3
C11		46	19	10	1.6	0.4	5.0
C11		46	18	20	2.3	0.7	7.5
C11		46	17	30	7.4	0.3	5.5
C11		46	16	50	11.2	1.0	10.7
C11		46	15	75	12.5	1.0	10.3
C11		46	14	100	20.1	1.5	23.4
C11		46	13	125	29.3	2.1	33.8
C11		46	12	150	31.3	2.3	39.9
C11		46	11	175	25.4	1.9	40.4
C11		46	10	200	34.7	2.4	46.9
C11		46	9	250	19.1	1.2	34.2
C11		46	8	300	40.3	2.9	60.2
C11		46	7	400	44.3	3.1	74.3
C11		46	6	500	46.1	3.3	84.9
C11		46	5	600	49.3	3.4	96.1
C11		46	4	800	50.7	3.5	121.3
C11		46	3	1000	51.0	3.6	134.1
C11		46	2	1200	50.9	3.6	130.0
C11		46	1	1446	42.8	3.1	121.4
G1	3-Jul-99	61	5	0	0.6	0.0	6.7
G1		61	4	10	1.9	0.0	7.1
G1		61	3	20	22.6	1.7	29.2
G1		61	2	30	29.1	2.0	37.3
G1		61	1	50	22.3	1.3	25.8
G2	3-Jul-99	63	7	0	0.6	0.3	10.1
G2		63	6	10	3.6	0.3	10.3
G2		63	5	20	22.5	1.8	33.3
G2		63	4	30	24.8	1.9	34.3
G2		63	3	50	14.3	1.0	17.4
G3	3-Jul-99	65	8	0	0.2	0.0	7.0
G3		65	7	5	0.2	0.3	9.0
G3		65	6	10	0.1	0.4	8.4
G3		65	5	20	9.9	1.2	16.9
G3		65	4	30	19.7	1.6	24.0
G3		65	3	50	36.9	2.2	41.8
G3		65	2	75	26.4	1.6	32.0
G3		65	1	100	52.2	3.0	65.9

APPENDIX B

Table B.2 continued. Dissolved nutrients in July 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
G6	3-Jul-99	70	17	0	1.1	0.4	3.4
G6		70	16	10	0.4	0.4	3.7
G6		70	15	20	3.7	0.8	6.7
G6		70	14	30	15.1	1.4	11.4
G6		70	13	50	12.7	1.2	12.8
G6		70	12	75	29.9	1.9	15.6
G6		70	11	100	18.8	1.4	13.0
G6		70	10	125	29.0	2.3	38.1
G6		70	9	150	24.3	2.2	41.5
G6		70	8	175	32.8	2.8	52.5
G6		70	7	200	33.5	2.8	54.2
G6		70	6	250	26.7	2.4	53.1
G6		70	5	300	37.1	3.2	67.7
G6		70	4	400	38.9	3.3	75.2
G6		70	3	500	33.4	2.9	73.2
G6		70	2	600	28.4	2.6	90.1
G6		70	1	800	42.9	3.6	109.3
G7	3-Jul-99	71	22	0	0.2	0.0	3.9
G7		71	21	5	0.2	0.2	4.8
G7		71	20	10	0.3	0.3	5.4
G7		71	19	20	0.3	0.4	7.9
G7		71	18	30	1.9	0.1	5.7
G7		71	17	50	8.9	0.9	13.3
G7		71	16	75	16.7	1.5	21.8
G7		71	15	100	22.0	1.7	32.3
G7		71	14	125	32.9	2.4	38.9
G7		71	13	150	34.2	2.5	43.1
G7		71	12	175	30.9	2.3	42.6
G7		71	11	200	16.1	1.0	28.6
G7		71	10	250	39.1	2.8	56.0
G7		71	9	300	40.8	2.9	62.5
G7		71	8	400	19.9	1.5	48.2
G7		71	7	500	45.6	3.3	85.5
G7		71	6	600	22.6	2.2	62.9
G7		71	5	800	47.6	3.5	137.7
G7		71	4	1000	47.8	3.5	136.9
G7		71	3	1200	47.8	3.5	154.7
G7		71	2	1500	28.4	2.2	111.5
G7		71	1	1769	45.9	3.4	185.9
BP2	6-Jul-99	94	9	4	1.0	0.1	4.5
BP2		94	8	6	0.4	0.1	4.1
BP2		94	7	10	0.4	0.4	5.1
BP2		94	6	15	1.7	0.4	5.3
BP2		94	5	18	4.9	0.4	7.4
BP2		94	4	30	20.5	1.7	15.5
BP2		94	3	50	21.9	2.0	29.4
BP2		94	2	75	17.5	1.4	27.6
BP2		94	1	96	31.5	2.5	45.5
BP3	6-Jul-99	91	10	0	0.8	0.3	3.4
BP3		91	9	10	0.8	0.2	5.9
BP3		91	8	20	4.4	0.0	7.3
BP3		91	7	30	14.7	1.1	16.6
BP3		91	6	50	26.4	1.9	26.4
BP3		91	5	75	35.9	2.0	33.3
BP3		91	4	100	26.8	2.4	42.7
BP3		91	3	125	26.4	2.3	45.2
BP3		91	2	150	18.7	1.5	36.8
BP3		91	1	161	32.5	2.8	47.4
BP4	6-Jul-99	90	19	0	3.5	0.1	4.4
BP4		90	18	10	0.6	0.3	5.1
BP4		90	17	20	10.4	1.2	14.7
BP4		90	16	30	20.0	1.7	21.8
BP4		90	15	50	15.7	1.3	12.4

APPENDIX B

Table B.2 continued. Dissolved nutrient in July 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
BP4	6-Jul-99	90	14	75	30.3	1.8	29.9
BP4		90	13	100	30.7	2.6	47.5
BP4		90	12	125	16.8	1.6	45.4
BP4		90	11	150	17.5	1.4	29.1
BP4		90	10	175	34.1	2.8	53.6
BP4		90	9	200	33.4	2.8	46.4
BP4		90	8	250	21.3	2.0	42.6
BP4		90	7	300	29.2	2.3	52.2
BP4		90	6	400	39.9	3.3	76.4
BP4		90	5	500	29.3	2.4	79.4
BP4		90	4	600	29.8	2.7	84.3
BP4		90	3	800	33.1	2.7	91.5
BP4		90	2	1000	29.7	2.7	95.7
BP4		90	1	1080	30.9	2.4	82.1
BP6	5-Jul-99	89	17	0	0.4	0.6	8.1
BP6		89	16	10	0.4	0.6	7.4
BP6		89	15	20	0.4	0.2	4.2
BP6		89	14	30	6.6	0.8	9.4
BP6		89	13	50	9.5	0.9	11.2
BP6		89	12	75	25.8	1.6	19.7
BP6		89	11	100	17.2	1.0	28.6
BP6		89	10	125	33.4	2.3	38.3
BP6		89	9	150	25.8	1.7	44.9
BP6		89	8	175	28.7	1.9	37.0
BP6		89	7	200	26.2	1.7	39.6
BP6		89	6	250	40.2	2.9	54.8
BP6		89	5	300	40.9	2.9	44.3
BP6		89	4	400	45.0	3.2	60.5
BP6		89	3	500	45.7	3.1	83.1
BP6		89	2	600	25.5	1.7	50.0
BP6		89	1	900	20.6	1.5	33.2
BP7	5-Jul-99	86	14	125	23.3	1.7	9.8
BP7		86	13	150	45.0	2.6	24.7
BP7		86	12	175	44.7	2.7	20.7
BP7		86	11	200	45.5	2.9	32.1
BP7		86	9	300	45.4	3.1	33.6
BP7		86	8	500	22.0	1.7	66.3
BP7		86	7	700	35.2	3.1	100.9
BP7		86	6	750	45.6	3.6	112.9
BP7		86	5	800	36.5	3.1	102.5
BP7		86	4	1000	19.3	1.7	113.4
BP7		86	3	1200	29.4	2.2	97.5
BP7		86	2	1500	45.8	3.5	113.4
BP7		86	1	2250	43.5	3.4	113.4
BP7		87	6	10	0.4	0.2	9.2
BP7		87	5	11	0.7	0.5	11.5
BP7		87	4	15	0.9	0.5	11.6
BP7		87	3	22	1.7	0.6	9.5
BP7		87	2	31	9.4	1.3	16.7
BP7		87	1	37	8.1	0.9	17.7

APPENDIX B

1999 DISSOLVED NUTRIENT RAW DATA SET

Table B.3 NO_3^-, HPO_4^{2-} and $Si(OH)_4$ for October 1999 on the west coast of Vancouver Island. All samples were collected and analyzed as outlined in methods section of Chapter 1. Dashed line (-) indicates that informaton is not available.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
B4	30-Sep-99	132	7	0	20.3	2.0	35.4
B4		132	6	10	11.3	1.7	29.3
B4		132	5	20	32.5	2.9	40.8
B4		132	4	30	27.2	3.0	40.3
B4		132	3	50	33.4	3.1	41.3
B4		132	2	75	39.3	3.3	46.4
B4		132	1	105	37.3	2.9	47.5
B6	1-Oct-99	130	8	0	9.2	1.0	25.4
B6		130	7	10	11.4	1.1	24.8
B6		130	6	20	8.4	1.4	28.0
B6		130	5	30	19.1	1.7	31.4
B6		130	4	50	19.8	1.7	31.6
B6		130	3	75	34.9	2.9	47.7
B6		130	2	100	30.4	2.6	45.1
B7	27-Sep-99	78	10	250	11.9	0.7	15.6
B7		78	9	300	29.6	2.3	32.7
B7		78	8	400	32.2	2.4	37.4
B7		78	7	500	12.5	1.0	19.3
B7		78	6	600	34.8	2.5	38.3
B7		78	5	800	39.7	2.9	36.3
B7		78	4	1000	41.5	3.0	40.4
B7		78	3	1200	40.4	2.9	27.9
B7		78	2	1500	47.3	3.5	48.6
B7		78	1	2000	47.4	3.7	49.0
C1	30-Sep-99	119	14	0	3.0	0.4	8.7
C1		119	11	10	25.1	1.8	37.7
C1		119	10	15	26.0	1.8	36.1
C1		119	6	40	26.9	2.1	33.7
C1		119	5	50	28.7	1.7	37.2
C1		119	4	75	23.5	1.8	31.4
C1		119	3	100	27.3	1.6	39.4
C1		119	2	125	25.5	1.8	38.6
C1		119	1	150	30.6	1.5	48.4
C4		115	12	0	17.5	1.9	31.4
C4		115	11	2	16.3	1.8	32.3
C4		115	10	5	17.7	1.8	29.8
C4		115	9	10	19.4	2.1	34.8
C4		115	8	20	13.9	1.7	28.2
C4		115	7	30	24.2	2.2	34.8
C4		115	6	50	24.6	2.1	37.1
C4		115	5	75	22.9	2.3	38.7
C4		115	4	100	30.2	2.5	49.8
C4		115	3	125	19.9	1.7	40.0
C4		115	2	150	32.7	2.8	55.4
C4		115	1	161	28.0	2.2	44.6
C7	29-Sep-99	110	9	0	9.0	0.6	17.3
C7		110	8	10	21.4	0.6	20.2
C7		110	7	20	100.7	2.3	61.3
C7		110	6	30	31.6	2.5	55.0
C7		110	5	50	28.4	2.1	-
C7		110	4	75	60.7	4.4	78.8
C7		110	3	100	27.2	2.4	46.4
C7		110	2	125	22.8	1.8	37.9
C7		110	1	bot	38.4	3.1	53.2

Table B.3 continued. Dissolved nutrients in October 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
C8	29-Sep-99	108	11	0	25.5	1.9	39.9
C8		108	10	10	13.3	0.7	26.6
C8		108	9	20	28.6	2.0	40.7
C8		108	8	30	10.4	1.1	19.4
C8		108	7	50	18.7	1.6	20.7
C8		108	6	75	26.6	1.6	26.8
C8		108	5	100	43.5	2.6	39.1
C8		108	3	150	51.4	3.1	61.8
C8		108	2	175	52.5	3.2	63.1
C8		108	1	188	43.7	2.9	52.7
C9	29-Sep-99	106	22	0	12.4	1.2	23.2
C9		106	21	2	18.7	1.7	22.1
C9		106	20	5	18.4	1.6	26.1
C9		106	19	10	12.3	1.2	22.2
C9		106	18	15	8.3	1.2	19.7
C9		106	17	20	7.2	4.7	16.3
C9		106	16	25	7.0	0.9	13.7
C9		106	15	30	6.5	0.9	11.3
C9		106	14	40	6.6	0.7	11.0
C9		106	13	50	11.9	1.4	13.3
C9		106	12	75	24.9	1.8	22.1
C9		106	11	100	28.8	1.7	26.7
C9		106	10	125	44.3	2.7	40.8
C9		106	8	175	46.2	3.1	52.6
C9		106	7	200	41.6	2.8	51.0
C9		106	6	250	25.9	2.1	48.4
C9		106	5	300	37.7	3.0	62.7
C9		106	4	400	41.4	3.3	72.9
C9		106	3	500	35.2	2.9	70.1
C9		106	2	600	45.0	3.6	91.0
C9		106	1	613	45.4	3.6	92.0
C11	29-Sep-99	104	20	0	7.7	0.9	57.1
C11		104	19	10	8.3	0.9	22.0
C11		104	18	20	24.3	0.5	21.0
C11		104	17	30	9.4	0.9	14.1
C11		104	16	50	13.7	1.2	12.1
C11		104	15	75	12.3	1.1	11.2
C11		104	13	125	34.6	2.2	37.2
C11		104	12	150	28.3	1.8	32.7
C11		104	11	175	38.1	2.4	43.1
C11		104	10	200	24.2	1.6	33.0
C11		104	9	250	48.8	2.9	66.1
C11		104	8	300	25.9	2.1	41.1
C11		104	7	400	27.9	2.0	49.7
C11		104	6	500	30.7	2.1	50.9
C11		104	5	600	43.3	3.5	80.2
C11		104	4	800	28.7	2.4	110.3
C11		104	3	1000	37.8	3.3	113.2
C11		104	2	1200	49.0	4.1	121.3
C11		104	1	1540	45.2	3.6	113.2
D1	23-Sep-99	21	4	0	6.6	1.0	29.2
D1		21	3	10	3.5	0.9	25.7
D1		21	2	20	21.5	2.1	36.4
D1		21	1	30	26.6	2.5	41.2
D2	23-Sep-99	22	5	0	4.8	0.5	26.9
D2		22	4	10	8.1	0.8	31.9
D2		22	3	20	17.7	1.7	35.7
D2		22	2	30	23.8	2.2	37.6
D2		22	1	40	26.3	2.7	47.7
D4	23-Sep-99	25	6	0	23.2	1.7	-
D4		25	5	10	32.8	2.3	41.4
D4		25	4	20	39.5	2.4	-
D4		25	3	30	40.1	2.6	-
D4		25	2	50	43.0	2.7	105.7

Table B.3 continued. Dissolved nutrients in October 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
D8	23-Sep-99	30	17	0	4.0	0.6	26.8
D8		30	16	10	6.2	0.8	24.7
D8		30	15	20	8.3	1.1	13.8
D8		30	14	30	19.4	1.5	20.2
D8		30	13	50	31.3	2.6	37.5
D8		30	12	75	98.8	6.5	91.7
D8		30	11	100	17.6	0.7	13.7
D8		30	10	125	33.1	2.4	34.7
D8		30	9	150	35.2	2.6	42.9
D8		30	8	175	38.5	2.8	50.3
D8		30	7	200	28.5	2.0	45.4
D8		30	6	250	27.9	1.9	48.1
D8		30	5	300	25.5	1.7	45.1
D8		30	4	400	28.8	1.9	52.6
D8		30	3	500	103.7	6.8	154.1
D8		30	2	600	31.9	2.5	66.0
D8		30	1	782	49.4	3.6	107.6
D10	24-Sep-99	32	20	0	1.1	0.2	16.7
D10		32	19	10	1.3	0.3	17.3
D10		32	18	20	2.7	0.3	9.4
D10		32	17	30	6.5	0.5	10.9
D10		32	16	50	6.4	0.6	10.0
D10		32	15	75	6.4	0.6	9.9
D10		32	14	100	18.1	1.5	18.7
D10		32	13	125	20.7	1.6	20.0
D10		32	12	150	19.7	1.4	23.9
D10		32	11	175	43.5	2.7	44.9
D10		32	10	200	25.0	2.0	27.8
D10		32	9	250	33.0	2.3	40.1
D10		32	8	300	20.5	1.5	38.4
D10		32	7	400	36.3	3.0	72.1
D10		32	6	500	22.6	1.6	57.9
D10		32	5	600	26.9	2.2	77.6
D10		32	4	800	29.0	2.6	99.1
D10		32	3	1000	46.0	3.7	113.5
D10		32	2	1200	45.9	3.6	113.5
D10		32	1	1475	32.7	2.7	113.6
G1	28-Sep-99	88	6	0	15.7	1.7	30.5
G1		88	5	10	16.1	1.8	30.5
G1		88	4	20	14.8	1.6	25.3
G1		88	3	30	25.3	2.7	38.4
G1		88	2	50	25.1	2.9	37.3
G1		88	1	55	26.3	2.9	38.5
G3	28-Sep-99	92	13	0	12.8	1.3	30.2
G3		92	12	2	13.7	1.5	31.2
G3		92	11	5	14.1	1.5	30.3
G3		92	10	10	8.7	0.9	-
G3		92	9	15	13.1	1.3	28.3
G3		92	8	20	17.5	1.8	40.3
G3		92	7	25	17.7	1.8	23.9
G3		92	6	30	18.3	1.7	-
G3		92	5	40	17.6	1.7	24.9
G3		92	4	50	23.8	2.3	30.6
G3		92	3	75	35.8	3.4	57.7
G3		92	2	100	37.5	3.1	52.3
G3		92	1	125	33.1	2.9	47.9
G7	28-Sep-99	98	24	0	4.2	0.7	15.3
G7		98	23	5	5.0	0.7	15.0
G7		98	22	10	5.6	0.8	16.1
G7		98	21	15	6.0	0.8	16.2
G7		98	20	20	7.4	0.9	15.2
G7		98	19	25	7.5	1.0	15.2
G7		98	18	30	7.9	1.0	-
G7		98	17	40	12.1	1.2	13.4
G7		98	16	50	9.7	1.1	23.9
G7		98	15	75	18.9	1.4	19.4
G7		98	14	100	36.1	2.3	33.9
G7		98	13	150	41.7	2.7	45.7

Table B.3 continued. Dissolved nutrients in October 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
G7	28-Sep-99	98	12	175	41.7	2.8	47.0
G7		98	11	200	45.8	2.9	58.6
G7		98	10	250	30.1	1.9	50.9
G7		98	9	300	24.1	1.9	53.3
G7		98	8	400	40.8	3.3	75.5
G7		98	7	500	34.6	2.9	90.7
G7		98	6	600	35.3	2.7	89.6
G7		98	5	800	44.1	3.5	113.3
G7		98	4	1000	33.1	2.6	110.9
G7		98	3	1200	31.1	2.5	113.4
G7		98	2	1500	21.8	1.9	113.5
G7		98	1	1800	25.8	1.9	108.2
J6	27-Sept-99	84	19	0	8.1	0.5	13.6
J6		84	18	10	15.5	1.6	22.9
J6		84	17	20	15.5	0.0	17.9
J6		84	16	30	13.9	1.3	18.2
J6		84	15	50	12.6	1.2	13.0
J6		84	14	75	9.4	0.5	9.4
J6		84	13	100	30.9	1.3	25.5
J8	28-Sep-99	81	20	0	5.1	1.1	14.1
J8		81	19	10	4.9	1.1	14.4
J8		81	17	30	10.0	1.4	18.6
J8		81	16	50	7.8	1.2	12.4
J8		81	15	75	15.3	1.8	19.8
J8		81	14	100	23.8	1.5	27.2
J8		81	13	125	20.4	1.2	24.1
J8		81	12	150	28.6	1.9	36.5
J8		81	11	175	38.3	2.4	45.9
J8		81	10	200	33.7	2.2	45.8
J8		81	9	250	35.4	2.4	55.2
J8		81	8	300	32.2	2.5	52.1
J8		81	7	400	23.3	1.9	58.1
J8		81	6	500	15.8	1.5	71.4
J8		81	5	600	28.0	2.4	77.1
J8		81	4	800	43.6	3.7	112.7
J8		81	3	1000	43.6	3.7	112.8
J8		81	2	1200	41.5	3.5	112.9
J8		81	1	1500	25.2	2.2	112.8
BP2	27-Sep-99	70	12	0	16.3	1.4	33.6
BP2		70	11	2	15.8	1.4	33.5
BP2		70	10	5	16.0	1.4	33.9
BP2		70	8	15	19.5	1.5	33.3
BP2		70	7	20	20.0	1.6	-
BP2		70	6	25	24.7	2.0	-
BP2		70	5	3	20.2	1.4	26.8
BP2		70	4	40	31.0	2.0	33.3
BP2		70	3	50	33.7	2.4	49.1
BP2		70	2	75	31.4	2.0	35.4
BP2		70	1	100	31.2	2.5	41.5
BP5	27-Sep-99	75	20	0	10.0	1.2	29.8
BP5		75	19	10	3.9	0.3	15.4
BP5		75	18	20	13.2	1.3	26.3
BP5		75	17	30	11.7	1.1	20.2
BP5		75	16	50	21.0	1.7	25.5
BP5		75	15	75	13.4	1.1	22.5
BP5		75	14	100	14.9	1.3	24.9
BP5		75	13	125	24.8	2.0	36.3
BP7	27-Sep-99	78	22	0	7.7	0.9	23.3
BP7		78	21	2	10.2	1.3	23.8
BP7		78	20	5	9.2	1.3	27.2
BP7		78	19	15	11.1	1.4	25.4
BP7		78	18	25	18.8	2.2	31.0
BP7		78	17	40	20.2	2.3	31.3
BP7		78	16	50	25.0	2.2	27.9
BP7		78	15	75	33.6	2.1	39.2
BP7		78	14	100	39.0	2.4	59.8
BP7		78	13	125	32.1	2.1	44.7

Table B.3 continued. Dissolved nutrients in October 1999.

Station	Date	Cast #	Niskin #	Depth m	NO_3^- µM	HPO_4^{2-} µM	$Si(OH)_4$ µM
BP7	27-Sep-99	78	12	150	41.7	2.9	54.3
BP7		78	11	175	41.7	2.9	58.4
BP7		78	10	200	53.5	3.3	65.4
BP7		78	9	250	28.1	2.1	48.8
BP7		78	8	300	42.5	3.3	72.5
BP7		78	7	400	44.4	3.5	72.7
BP7		78	6	500	34.4	2.8	73.1
BP7		78	5	600	32.6	2.8	88.3
BP7		78	3	800	27.5	2.1	88.5
BP7		78	2	1000	43.4	3.6	112.9
BP7		78	1	b-10	38.6	3.2	109.9
CPE2	26-Sep-99	66	9	0	13.0	1.4	24.3
CPE2		66	8	10	6.6	0.8	17.9
CPE2		66	7	20	11.5	1.3	22.4
CPE2		66	6	30	16.6	1.7	27.0
CPE2		66	5	50	19.1	2.0	28.1
CPE2		66	4	75	21.2	2.0	30.0
CPE2		66	3	100	28.7	2.8	41.2
CPE2		66	2	100	30.2	2.7	39.8
CPE2		66	1	121	31.4	2.9	49.1
CS7	26-Sep-99	42	6	0	8.9	0.8	19.9
CS7		42	5	10	7.8	0.8	18.8
CS7		42	4	20	10.2	1.0	22.1
CS7		42	3	30	23.5	1.6	29.2
CS7		42	2	50	73.3	4.6	93.2
CS7		42	1	60	72.6	4.6	91.8
CS3B	26-Sep-99	49	12	0	4.4	0.7	16.7
CS3B		49	11	10	2.8	0.7	13.2
CS3B		49	10	20	3.0	0.6	12.6
CS3B		49	9	30	3.9	1.0	15.6
CS3B		49	8	50	15.3	1.7	23.5
CS3B		49	7	75	25.3	2.8	32.3
CS3B		49	6	100	23.2	1.4	26.8
CS3B		49	5	125	41.7	2.7	48.3
CS3B		49	4	150	41.7	2.9	50.3
CS3B		49	3	175	31.6	2.0	40.5
CS3B		49	2	200	33.2	2.0	40.8
CS3B		49	1	210	38.3	2.5	50.0
Q3	26-Sep-99	63	17	0	2.5	0.6	49.0
Q3		63	16	10	6.6	1.0	15.4
Q3		63	15	25	4.1	0.3	7.7
Q3		63	14	35	3.6	0.1	5.9
Q3		63	13	45	11.9	1.5	16.0
Q3		63	12	48	13.4	1.5	17.8
Q3		63	11	50	14.2	1.5	18.2
Q3		63	10	75	28.1	2.1	32.3
Q3		63	9	100	38.4	2.2	35.9
Q3		63	8	125	41.6	2.6	46.4
Q3		63	7	150	43.8	2.9	52.3
Q3		63	6	175	52.1	3.0	61.4
Q3		63	5	200	52.4	3.0	62.6
Q3		63	4	250	23.4	1.9	41.7
Q3		63	3	300	40.7	3.2	68.8
Q3		63	2	400	23.3	2.0	69.2
Q3		63	1	500	42.9	3.4	84.0

APPENDIX C

1999 RAW DATA SET

Table C.1 Chlorophyll *a* (mg m^{-3}) in May 1999 off the west coast of Vancouver Island. All samples were filtered onto 0.7 μm glass fiber filters unless otherwise indicated by ∗ which were filtered onto 5.0 μm polycarbonate filters. (-) indicates data not available.

Station	Date	Cast #	Niskin #	Depth (m)	Chl *a* (mg m^{-3})
B2	4-May-99	4	5	0	4.4
			4	10	4.9
			3	20	2.1
			1	50	1.0
B4	4-May-99	6	7	0	14.5
			6	10	8.2
			5	20	6.0
			4	30	2.6
B6	5-May-99	8	7	0	8.3
			6	10	12.9
			5	20	6.3
			4	30	2.5
			3	50	0.6
B8	5-May-99	14	5	0	0.9
			4	10	1.3
			3	20	2.6
			2	30	4.7
			1	50	1.7
B10	6-May-99	46	9	0	1.0
			8	10	1.1
			7	20	0.6
			6	30	0.6
			5	50	0.5
B12	6-May-99	44	15	0	0.6
			14	10	0.7
			13	20	0.5
			11	50	0.8
B14	6-May-99	40	18	0	0.5
			17	10	0.6
			16	20	0.7
			15	30	0.6
			14	50	0.7
B16	6-May-99	43	12	0	0.4
			11	10	0.4
			10	20	0.5
			9	30	0.4
			8	40	0.5
			7	50	1.1
B16∗	6-May-99	43	12	0	0.7
C1	5-May-99	9	12	0	2.9
			11	2	5.5
			10	5	8.3
			8	15	11.5
			7	2	6.1
C1∗	5-May-99	9	12	0	3.7
C2	5-May-99	21	7	0	2.6
			6	10	3.2
			5	20	3.3
			4	30	0.5
			3	50	0.3

Table C.1 continued

Station	Date	Cast #	Niskin #	Depth (m)	Chl *a* (mg m^{-3})
C4	5-May-99	23	11	0	2.9
			10	5	1.1
			9	10	0.6
			8	15	1.3
			7	20	3.6
			6	30	0.4
C4*	5-May-99	23	11	0	0.1
C7	5-May-99	27	10	0	2.0
			8	10	0.6
			6	20	0.9
			5	30	0.7
			4	50	0.7
C8	5-May-99	28	12	0	1.3
			11	10	1.2
			10	20	0.6
			9	30	0.6
			8	50	0.8
C9	5-May-99	30	16	0	1.0
			15	5	1.0
			14	10	1.2
			14	20	0.4
			13	25	0.3
			12	30	0.6
C11	5-May-99	36	18	0	0.5
			17	10	0.5
			16	20	0.9
			15	30	0.8
			14	50	1.4
D2	6-May-99	48	5	0	4.6
			4	10	4.3
			3	20	4.6
			2	30	1.2
			1	41	1.6
D4	6-May-99	50	7	0	3.5
			6	10	3.8
			5	20	0.3
			4	30	0.2
			3	50	0.3
G1	7-May-99	52	5	0	3.8
			4	10	2.1
			3	20	1.7
			2	30	1.8
			1	50	1.2
G2	7-May-99	53	7	0	1.2
			6	10	1.6
			5	20	1.9
			4	30	0.3
			3	50	0.2
G3	7-May-99	65	12	0	0.8
			11	5	0.8
			10	10	0.9
			9	20	0.9
			7	30	0.9
			6	40	0.6
G3*	7-May-99	65	12	0	0.1
G4	7-May-99	56		0	0.9
				10	1.2
				20	1.0
				30	0.7
				50	0.1
G7	6-May-99	59	16	0	0.6
			15	5	0.6
			14	10	0.4
			13	20	0.3
			12	30	0.5
			11	40	0.8
G7*	6-May-99	59	16	0	0.1

Table C.1 continued

Station	Date	Event #	Niskin #	Depth (m)	Chl *a* (mg m^{-3})
G9	7-May-99	64	16	0	0.2
			15	10	0.2
			14	20	0.3
			13	30	0.4
			12	50	2.7
J1	10-May-99	124	6	0	8.4
			5	10	8.2
			4	20	7.6
			3	30	1.8
			2	50	0.4
J2	10-May-99	125	6	0	7.5
			5	10	7.9
			4	20	2.2
			3	30	0.7
			2	50	0.4
J4	11-May-99	128	9	0	3.2
			8	10	3.0
			7	20	2.4
			6	30	0.9
			5	50	0.3
J6	11-May-99	131	17	0	2.5
			16	10	2.5
			15	20	1.6
			14	30	0.6
			13	50	0.4
J8	11-May-99	134	17	0	3.2
			16	10	3.4
			15	20	1.1
			14	30	0.8
			13	50	0.2
BP2	10-May-99	118	10	0	3.8
			9	2.5	4.0
			8	5	3.9
			7	10	4.1
			6	15	3.7
			5	20	4.2
BP2*	10-May-99	118	10	0	2.8
BP4	7-May-99	117	17	0	3.7
			16	10	4.3
			15	20	5.7
			14	30	1.6
			13	50	1.0
BP6	10-May-99	114	16	0	3.8
			15	10	3.3
			14	20	1.8
			13	30	1.2
			12	50	0.4
BP7	10-May-99	123	16	0	0.8
			15	2.5	0.8
			14	5	0.8
			13	10	0.8
			12	15	0.6
			11	20	0.6
			8	100	0.1
BP7*	10-May-99	123	16	0	0.1
BP8	10-May-99	110	21	0	0.6
			20	10	0.6
			19	20	0.4
			18	30	0.5
			17	50	0.3
JI22	9-May-99	101	15	0	3.3
			14	10	5.1
			13	20	7.3
			12	30	2.7
			11	50	1.1

Table C.1 continued

Station	Date	Event #	Niskin #	Depth (m)	Chl *a* (mg m^{-3})
CS1	8-May-99	67	14	0	8.0
			13	10	7.8
			12	20	8.3
			11	30	6.9
			10	50	0.7
CS3	8-May-99	73	11	0	3.3
			10	10	3.2
			9	20	1.8
			8	30	9.8
			7	50	0.4
CS3B	9-May-99	95	11	0	1.9
			10	10	1.6
			9	20	1.4
			8	30	0.9
			7	50	0.5
			7	50	0.4
CS3B*	9-May-99	95	11	0	1.1
CS5	8-May-99	77	6	0	5.7
			5	10	5.1
			4	20	5.9
			3	30	4.2
			2	50	5.0
CS7	8-May-99	82	6	0	5.2
			5	10	5.4
			4	20	5.0
			3	30	4.2
			2	50	2.3
CS9	8-May-99	88	11	0	5.1
			10	10	6.5
			9	20	6.1
			8	30	5.0
			7	50	2.2
CPE2	9-May-99	107	8	0	5.0
			7	10	5.9
			6	20	2.5
			5	30	0.4
			4	50	0.3
CS1B	9-May-99	93	6	0	5.7
			5	10	4.6
			4	20	5.7
			3	30	2.9
			2	50	2.3
MP8	12-May-99	137	17	0	0.7
			16	10	0.7
			15	20	0.6
			14	30	0.2
			13	50	0.3
P4	12-May-99	142	16	0	0.6
			15	10	0.6
			14	20	0.6
			13	30	0.4
			12	50	0.3
P6	12-May-99	142	16	0	0.6
			15	10	0.5
			14	20	0.6
			13	30	0.3
			12	50	0.3

APPENDIX C

Table C.2 Chlorophyll *a* (mg m^{-3}) in July 1999 off the west coast of Vancouver Island. All samples were filtered onto 0.7 μm glass fiber filters unless otherwise indicated by ✱ which were filtered onto a 5.0 μm polycarbonate filters.

Station	Date	Cast #	Niskin #	Depth (m)	Chl *a* (mg m^{-3})
B6	30-Jun-99	6	9	0	2.50
			8	5	2.45
			7	10	2.27
			6	20	1.80
			5	30	0.94
			4	50	0.34
			3	75	0.17
B8	30-Jun-99	8	9	0	8.32
			8	10	4.81
			7	20	0.94
			6	30	0.79
			5	50	0.35
B16	1-Jul-99	18	5	0	0.85
			4	10	0.87
			3	20	0.90
			2	30	0.42
			1	40	0.05
C1	30-Jun-99	33	7	0	6.47
			6	10	4.20
			5	20	1.02
			4	30	1.06
			3	50	0.19
C4	1-Jul-99	36	14	0	4.16
			12	6	3.77
			11	5	4.27
			9	18	0.54
			8	34	0.18
			7	41	0.22
C4✱	1-Jul-99	36	13	5	3.45
C5	2-Jul-99	38	6	0	3.47
			5	10	2.93
			4	20	1.22
			3	30	0.70
			2	50	0.32
C6	2-Jul-99	39	7	0	0.70
			6	10	0.74
			5	20	2.07
			4	30	0.98
			3	50	0.23
C7	2-Jul-99	40	8	0	0.56
			7	10	0.74
			6	20	1.46
			5	30	0.83
			4	50	0.16
C8	2-Jul-99	41	11	0	0.44
			10	10	0.41
			9	20	1.08
			8	30	0.97
			7	50	0.19
C9	2-Jul-99	42	16	0	0.46
			15	10	0.41
			14	20	0.55
			13	30	0.60
			12	50	0.52
C9✱	2-Jul-99	42	16	0	0.12
C11	2-Jul-99	46	20	0	0.43
			19	10	0.29
			18	20	0.34
			17	30	0.38
			16	50	0.74

Table C.2. continued

Station	Date	Cast #	Niskin #	Depth (m)	Chl *a* (mg m^{-3})
G1	3-Jul-99	61	5	0	6.66
			4	10	6.24
			3	20	0.60
			2	30	0.27
			1	50	0.12
G2	3-Jul-99	63	7	0	7.82
			6	10	4.81
			5	20	0.40
			4	30	0.09
			3	50	0.15
G3	3-Jul-99	65	8	0	1.82
			7	5	2.01
			6	10	2.02
			5	20	0.81
			4	30	0.32
			3	40	0.05
G3*	3-Jul-99	65	8	0	1.34
G6	3-Jul-99	70	17	0	1.98
			16	10	2.00
			15	20	1.73
			14	30	0.87
			13	50	0.27
G7	3-Jul-99	71	22	0	1.07
			21	5	0.89
			20	10	0.92
			19	20	0.68
			18	30	1.34
			17	40	0.32
BP2	6-Jul-99	94	9	3.5	1.60
			8	6	3.13
			7	10	3.43
			6	15	3.31
			5	18	2.51
			5	18	2.07
BP3	6-Jul-99	91	10	0	1.90
			9	10	4.70
			8	20	3.93
			7	30	1.59
			6	50	0.20
BP4	6-Jul-99	90	19	0	2.93
			18	10	3.70
			17	20	3.05
			15	50	0.34
			16	30	0.82
BP6	5-Jul-99	89	17	0	2.80
			16	10	2.64
			15	20	1.49
			14	30	1.21
			13	50	0.31
BP7	5-Jul-99	86	6	10	3.93
			5	11	4.24
			4	15	3.47
			3	22	2.34
			2	31	0.64
			1	37	0.39
BP7*	5-Jul-99	86	6	0	1.34

APPENDIX C

Table C.3. Chlorophyll *a* (mg m^{-3}) in October 1999 off the west coast of Vancouver Island. All samples were filtered onto 0.7 μm glass fiber filtes unless otherwise indicated by ✳ which were filtered onto a 5.0 μm polycarbonate filters.

Station	Date	Cast #	Niskin #	Depth (m)	Chl *a* (mg m^{-3})
B4	30-Sep-99	131	7	0	2.66
			5	20	1.08
			4	30	0.75
			3	50	0.39
B6	30-Sep-99	130	8	0	3.12
			7	10	2.91
			6	20	1.76
			5	30	0.72
			4	50	0.29
C1	30-Sep-99	119	14	0	4.51
			13	2	4.58
			12	5	4.70
			10	15	2.89
			8	25	1.08
			6	40	0.32
C1✳	30-Sep-99		14	0	1.92
C4	30-Sep-99	115	12	0	4.89
			11	2	5.31
			10	5	4.93
			8	20	1.01
			7	30	1.15
			6	50	0.46
C4✳	30-Sep-99		12	0	3.67
C7	29-Sep-99	110	9	0	6.85
			8	10	7.16
			7	20	2.71
			6	30	1.56
			5	50	0.31
C8	29-Sep-99	108	11	0	4.85
			10	10	4.77
			9	20	2.93
			8	30	1.96
			7	50	0.35
C9	29-Sep-99	106	22	0	4.97
			21	2	5.47
			20	5	6.12
			18	15	3.31
			16	25	0.50
			14	40	0.17
C9✳	29-Sep-99	106	22	0	3.54
C11	29-Sep-99	104	20	0	5.20
			19	10	4.77
			18	20	1.88
			17	30	0.89
			16	50	0.23
D1	23-Sep-99	21	4	0	9.55
			3	5	8.90
			2	10	0.93
			1	30	0.42
D2	23-Sep-99	22	5	0	6.62
			4	10	6.51
			3	20	1.58
			2	30	0.42
D4	23-Sep-99	25	6	0	5.93
			5	10	1.90
			4	20	1.42
			3	30	0.83
			2	50	0.31

Table C.3. continued

Station	Date	Cast #	Niskin #	Depth (m)	Chl *a* (mg m^{-3})
D8	23-Sep-99	30	17	0	7.62
			16	10	3.85
			15	20	0.48
			14	30	0.16
			13	50	0.12
D10	24-Sep-99	32	20	0	6.89
			19	10	7.66
			18	20	1.76
			17	30	0.25
			16	50	0.12
G1	28-Sep-99	88	6	0	7.43
			5	10	7.20
			4	20	2.56
			3	30	0.11
			2	50	0.13
G3	28-Sep-99	92	13	0	8.16
			12	2	7.66
			11	5	8.74
			9	15	4.69
			7	25	0.40
			5	40	0.13
G3*	28-Sep-99		13	0	5.35
G7	28-Sep-99	98	24	0	0.78
			24	0	1.90
			23	5	1.94
			21	10	1.72
			19	25	1.62
			17	40	0.54
G7*	28-Sep-99		24	0	1.50
J6	27-Sep-99	84	19	0	2.76
			18	10	3.00
			17	20	2.53
			16	30	1.72
			15	50	0.13
J8	27-Sep-99	81	20	0	1.79
			19	10	1.94
			18	20	2.69
			17	30	2.83
			16	50	0.28
BP2	26-Sep-99	70	12	0	6.08
			11	2	6.08
			10	5	5.97
			8	15	3.89
			6	25	1.47
			4	40	0.37
BP2*	26-Sep-99		12	0	4.66
BP5	27-Sep-99	75	20	0	8.74
			19	10	7.28
			18	20	3.20
			17	30	1.32
			16	50	0.13
BP7	27-Sep-99	78	22	0	9.40
			21	2	10.01
			20	5	9.70
			19	15	1.90
			18	25	0.32
			17	40	0.26
BP7*	27-Sep-99		22	0	3.24
CS7	25-Sep-99	42	6	0	1.95
			5	10	2.30
			4	20	2.09
			3	30	0.25
			2	50	0.05

Table C.3. continued

Station	Date	Cast #	Niskin #	Depth (m)	Chl a (mg m^{-3})
CPE2	26-Sep-99	66	9	0	4.51
			8	10	4.20
			7	20	2.08
			6	30	1.73
			5	50	0.67
CS3B	26-Sep-99	49	12	0	1.50
			11	10	1.57
			10	20	1.69
			9	30	1.36
			8	50	0.07
Q3	26-Sep-99	63	17	0	1.38
			15	25	0.37
			14	35	0.16
			13	45	0.28
			12	48	0.10
			11	50	0.09
Q3*	26-Sep-99	63	17	0	0.80

APPENDIX D

PRIMARY PRODUCTIVITY FOR 1999

Table D.1 Integrated (100-1% surface light) daily primary productivity (g C m^{-2} d^{-1}) in 1999 for July and October off the west coast of Vancouver Island.

Date	Station	Daily Production
29 June	C1	0.2
30 June	C4	2.0
07 July	G3	0.8
01 July	C9	0.4
03 July	G7	0.9
05 July	BP7	1.9
30 Sept.	C1	0.6
30 Sept.	C4	0.7
38 Sept.	G3	1.6
26 Sept.	BP2	0.6
29 Sept.	C9	0.6
28 Sept.	G7	0.3
27 Sept.	BP7	0.8

APPENDIX E

Sampling Stations

In addition to specific time series and process study stations, water samples were taken at additional stations along transects off the west coast of Vancouver Island. Tables E.1-E.6 show latitude, longitude and water depth for all stations sampled during cruises in 1997 and 1998. In this thesis data are presented for 1997 and 1998 for La Pérouse Bank, Barkley Canyon, Estevan Point and the Brooks Peninsula transects only. Physical, chemical, and biological data are presented in Chapter 1 and size-fractionated phytoplankton biomass and primary productivity in Chapter 2. All raw data for the above transects and the additional stations sampled during each cruise are archived in the Institute of Ocean Science's database.

During three cruises in 1999 a reduced number of stations were sampled. Tables E.7-E.9 show latitude, longitude and water depth data of all stations sampled in 1999. Data for 1999 are presented in Appendices B, C and D and also archived in the database at the Institute of Ocean Science (Sidney, BC).

APPENDIX E

Table E.1 Location and water depth of stations occupied during 08-24 April 1997 (Cruise ID#9707) off the west coast of Vancouver Island. Under the station column, B indicates La Pérouse Bank, C indicates Barkley Canyon, D indicates D Line, G indicates Estevan Point, BP indicates Brooks Peninula and CS indicates Cape Scott transects. See Figure 1.1 for location of transects.

Transect	Station	Latitude deg° min' sec" N	Longitude deg° min' sec" W	Bottom Depth (m)
La Pérouse Bank	B2	48° 39' 00"	125° 02' 24"	56
	B8	48° 25' 18"	125° 28' 39"	135
	B9	48° 22' 00"	125° 34' 48"	153
	B11	48° 15' 12"	125° 47' 45"	219
	B12	48° 12' 55"	125° 51' 54"	450
	B14	48° 08' 29"	126° 00' 00"	966
	B16	48° 00' 32"	126° 17' 00"	1530
Barkley Canyon	C1	48° 28' 59"	125° 15' 14"	156
	C2	48° 48' 41"	125° 30' 57"	111
	C4	48° 43' 28"	125° 40' 48"	166
	C7	48° 32' 58"	126° 00' 30"	129
	C8	48° 29' 27"	126° 07' 06"	201
	C9	48° 25' 24"	126° 13' 42"	659
	C10	48° 22' 24"	126° 20' 12"	1115
	C11	48° 18' 57"	126° 26' 42"	1330
D Line	D2	48° 58' 21"	125° 47' 03"	45
	D4	48° 53' 10"	125° 57' 00"	60
	D7	48° 42' 40"	126° 16' 48"	463
	D9	48° 35' 41"	126° 30' 00"	1100
Estevan Point	G1	49° 20' 30"	126° 35' 00"	60
	G3	49° 15' 00"	126° 43' 42"	126
	G4	49° 11' 18"	126° 49' 24"	150
	G5	49° 07' 24"	126° 55' 18"	250
	G6	49° 03' 30"	127° 01' 12"	972
	G7	48° 59' 24"	127° 07' 12"	1750
Brooks Peninsula	BP2	50° 04' 00"	127° 54' 12"	99
	BP3	50° 03' 12"	127° 55' 18"	139
	BP4	50° 04' 24"	127° 58' 06"	1090
	BP5	50° 00' 00"	128° 00' 00"	1230
	BP6	49° 56' 12"	128° 05' 30"	1730
	BP7	49° 52' 24"	128° 11' 12"	2200
Cape Scott	J023	50° 39' 48"	129° 01' 54"	1967
	CS2B	50° 55' 59"	128° 59' 52"	64
	CPE1	51° 00' 00"	127° 50' 00"	158
	CPE2	50° 43' 00"	128° 40' 00"	123

APPENDIX E

Table E.2 Location and water depth of stations occupied during 14–28 July 1997 (Cruise ID#9713) off the west coast of Vancouver Island. Under the station column, A indicates Juan de Fuca canyon, B indicates La Pérouse Bank, C indicates Barkley Canyon, G indicates Estevan Point and BP indicates Brooks Peninula transect. See Figure 1.1 for location of transects.

Transect	Station	Latitude deg° min' sec" N	Longitude deg° min' sec" W	Depth (m)
Juan de Fuca Canyon	A1	48° 29' 14"	124° 43' 39"	264
	A4	48° 19' 22"	125° 04' 07"	175
	A6	48° 12' 38"	125° 17' 12"	112
	A10	47° 59' 01"	125° 43' 24"	950
La Pérouse Bank	B2	48° 39' 00"	125° 02' 24"	56
	B8	48° 25' 18"	125° 28' 39"	135
	B9	48° 22' 00"	125° 34' 48"	153
	B10	48° 18' 34"	125° 41' 21"	151
	B12	48° 12' 55"	125° 51' 54"	450
	B14	48° 08' 29"	126° 00' 00"	966
	B16	48° 00' 32"	126° 17' 00"	1530
Barkley Canyon	C1	48° 28' 59"	125° 15' 14"	156
	C2	48° 48' 41"	125° 30' 57"	111
	C4	48° 43' 28"	125° 40' 48"	166
	C7	48° 32' 58"	126° 00' 30"	129
	C8	48° 29' 27"	126° 07' 06"	201
	C9	48° 25' 24"	126° 13' 42"	659
	C10	48° 22' 24"	126° 20' 12"	1115
	C11	48° 18' 57"	126° 26' 42"	1330
D Line	D2	48° 58' 21"	125° 47' 03"	45
	D4	48° 53' 10"	125° 57' 00"	60
	D7	48° 42' 40"	126° 16' 48"	463
	D9	48° 35' 41"	126° 30' 00"	1100
Estevan Point	G1	49° 20' 30"	126° 35' 00"	60
	G3	49° 15' 00"	126° 43' 42"	126
	G4	49° 11' 18"	126° 49' 24"	150
	G5	49° 07' 24"	126° 55' 18"	250
Brooks Peninsula	BP1	50° 04' 48"	127° 52' 48"	32
	BP2	50° 04' 00"	127° 54' 12"	99
	BP3	50° 03' 12"	127° 55' 18"	139
	BP4	50° 04' 24"	127° 58' 06"	1090
	BP5	50° 00' 00"	128° 00' 00"	1230
	BP6	49° 56' 12"	128° 05' 30"	730
	BP7	49° 52' 24"	128° 11' 12"	2200

APPENDIX E

Table E.3 Location and water depth of stations occupied during 20–27 October 1997 (Cruise ID#9737) off the west coast of Vancouver Island. Under the station column, B indicates La Pérouse Bank, C indicates Barkley Canyon, D indicates Line D, G indicates Estevan Point and BP indicates Brooks Peninula. See Figure 1.1 for location of transects.

Transect	**Station**	**Latitude** deg°min' sec" N	**Longitude** deg°min' sec" W	**Depth** (m)
La Pérouse Bank	B2	48° 39' 36"	125° 02' 28"	145
	B8	48° 25' 17"	125° 28' 43"	145
	B9	48° 22' 00"	125° 34' 49"	151
	B10	48° 18' 35"	125° 41' 13"	153
	B14	48° 08' 27"	125° 00' 07"	1185
Barkley Canyon	C1	48° 28' 59"	125° 15' 14"	156
	C4	48° 43' 28"	125° 40' 48"	166
	C7	48° 32' 58"	126° 00' 30"	129
	C8	48° 29' 27"	126° 07' 06"	201
	C9	48° 25' 24"	126° 13' 42"	656
	C10	48° 22' 24"	126° 20' 12"	1115
	C11	48° 18' 57"	126° 26' 42"	1330
D Line	D1	49° 00" 06"	125° 43' 48"	33
	D2	48° 58' 21"	125° 47' 03"	45
	D4	48° 53' 10"	125° 57' 00"	60
	D6	48° 46' 11"	126° 10' 12"	137
	D7	48° 42' 40"	126° 16' 48"	463
Estevan Point	G1	49° 20' 30"	126° 35' 00"	60
	G2	49° 18' 42"	126° 38' 06"	102
	G3	49° 15' 00"	126° 43' 42"	126
	G4	49° 11' 18"	126° 49' 24"	150
	G5	49° 07' 24"	126° 55' 18"	250
	G6	49° 03' 30"	127° 01' 12"	972
	G7	48° 59' 24"	127° 07' 12"	1750
Brooks Peninsula	BP1	50° 04' 48"	127° 52' 48"	32
	BP2	50° 04' 00"	127° 54' 12"	99
	BP3	50° 03' 12"	127° 55' 18"	139
	BP4	50° 04' 24"	127° 58' 06"	1090
	BP5	50° 00' 00"	128° 00' 00"	1230
	BP6	49° 56' 12"	128° 05' 30"	1730
	BP7	49° 52' 24"	128° 11' 12"	2200

APPENDIX E

Table E.4 Location and water depth of stations occupied during 11-25 May 1998 cruise (Cruise ID# 9810) off the west coast of Vancouver Island. Under the station column, B indicates La Pérouse Bank, C indicates Barkley Canyon, G indicates Estevan Point, H indicated H Line, J indicates J Line, BP indicates Brooks Peninula and CS indicates Cape Scott transect. See Figure 1.1 for location of transects.

Transect	**Station**	**Latitude** deg° min' sec" N	**Longitude** deg° min' sec" W	**Depth** (m)
La Pérouse Bank	B7	48° 25' 41"	125° 28' 06"	160
	B8	48° 25' 18"	125° 28' 39"	145
	B16	48° 00' 32"	126° 17' 00"	1530
Barkley Canyon	C1	48° 50' 26"	125° 27' 44"	156
	C2	48° 48' 41"	125° 30' 57"	111
	C3	48° 46' 57"	125° 34' 14"	120
	C7	48° 32' 58"	126° 00' 30"	129
	C8	48° 29' 27"	126° 07' 06"	201
	C9	48° 25' 24"	126° 13' 42"	659
	C11	48° 18' 57"	126° 26' 42"	1330
	C12	48° 15' 00"	126° 40' 00"	1000
Estevan Point	G1	49° 20' 30"	126° 35' 00"	60
	G2	49° 18' 42"	126° 38' 06"	105
	G3	49° 15' 00"	126° 43' 42"	126
	G6	49° 03' 30"	127° 01' 12"	972
	G7	48° 59' 24"	127° 07' 12"	1750
	G9	48° 51' 10"	127° 19' 21"	2081
H Line	H2	49° 32' 15"	126° 47' 17"	41
	H3	49° 28' 37"	126° 52' 54"	97
	H5	49° 21' 16"	126° 04' 45"	151
	H7	49° 13' 38"	126° 16' 07"	1001
	H9	49° 05' 31"	126° 28' 44"	2079
J Line	J2	49° 42' 40"	126° 05' 18"	150
	J4	49° 35' 25"	126° 16' 46"	150
	J6	49° 27' 29 "	126° 28' 35"	1001
Brooks Peninsula	BP2	50° 04' 00"	127° 54' 12"	99
	BP4	50° 04' 24"	127° 58' 06"	1090
	BP5	50° 00' 00"	128° 00' 00"	1230
	BP6	49° 56' 12"	128° 05' 30"	1730
	BP7	49° 52' 24"	128° 11' 12"	2200
	BP8	49° 48' 36"	128° 16' 48"	>2200
	BP9	49° 44' 47"	128° 22' 48"	>2200
Cape Scott	CS3B	51° 00' 00"	128° 50' 48"	150

APPENDIX E

Table E.5 Location and water depth of stations occupied during 14–26 July 1998 (Cruise ID#9823) off the west coast of Vancouver Island. Under the station column, A indicates Juan de Fuca canyon, B indicates La Pérouse Bank, C indicates Barkley Canyon, D indicates D Line, G indicates Estevan Point, BP indicates Brooks Peninula and ER indicated Endeavor Ridge transect. See Figure 1.1 for location of transects.

Transect	**Station**	**Latitude** deg° min' sec" N	**Longitude** deg° min' sec" W	**Depth** (m)
Juan de Fuca Canyon	A1	48° 29' 14"	124° 43' 39"	264
	A2	48° 26' 15"	124° 51" 19"	312
	A4	48° 19' 22"	125° 04' 07"	175
	A6	48° 12' 38"	125° 17' 12"	112
	A8	48° 05' 47"	125° 30' 24"	142
La Pérouse Bank	C1	48° 28' 59"	125° 15' 14"	156
	B16	48° 00' 32"	126° 17' 00"	1530
Barkley Canyon	C1	48° 50" 26"	125° 27' 44"	94
	C2	48° 48' 41"	125° 30' 57"	111
	C7	48° 32' 58"	126° 00' 30"	129
	C8	48° 29' 27"	126° 07' 06"	201
	C9	48° 25' 24"	126° 13' 42"	659
	C10	48° 22' 24"	126° 20' 12"	1115
	C11	48° 18' 57"	126° 26' 42"	1330
D Line	D1	48° 49' 06"	125° 43" 48"	33
	D2	48° 58' 21"	125° 47' 03"	45
	D4	48° 53' 10"	125° 57' 00"	60
	D7	48° 42' 40"	126° 16' 48"	463
	D9	48° 35' 41"	126° 30' 00"	1100
Estevan Point	G1	49° 20' 30"	126° 35' 00"	60
	G2	49° 18' 42"	126° 38' 06"	105
	G3	49° 15' 00"	126° 43' 42"	126
	G4	49° 11' 18"	126° 49' 24"	150
	G5	49° 07' 24"	126° 55' 18"	258
	G7	48° 59' 24"	127° 07' 12"	1800
Brooks Peninsula	BP1	50° 04' 48"	127° 52' 48"	32
	BP2	50° 04' 00"	127° 54' 12"	99
	BP3	50° 03' 12"	127° 55' 18"	139
	BP4	50° 04' 24"	127° 58' 06"	1090
	BP5	50° 00' 00"	128° 00' 00"	1230
	BP6	49° 56' 12"	128° 05' 30"	1730
	BP7	49° 52' 24"	128° 11' 12"	2200
Endeavor Ridge	ER01	47° 57' 29"	129° 05' 03"	2200
	M3	50° 05' 23"	128° 10' 12"	1180

APPENDIX E

Table E.6 Location and water depth of stations occupied during the 05–16 October 1998 cruise (Cruise ID#9836) off the west coast of Vancouver Island. Under the station column, indicates La Pérouse Bank, C indicates Barkley Canyon, G indicates Estevan Point, BP indicates Brooks Peninula and CS indicated Cape Scott. See Figure 1.1 for location of transects.

Transect	Station	Latitude deg° min' sec" N	Longitude deg° min' sec" W	Depth (m)
La Pérouse Bank	C1	48° 28' 59"	125° 15' 14"	156
	B16	48° 00' 32"	126° 17' 00"	1530
Barkley Canyon	C1	48° 50' 26"	125° 27' 44"	94
	C2	48° 48' 41"	125° 30' 57"	111
	C4	48° 43' 28"	125° 40' 48"	167
	C7	48° 32' 58"	126° 00' 30"	129
	C8	48° 29' 27"	126° 07' 06"	201
	C9	48° 25' 24"	126° 13' 42"	659
	C10	48° 22' 24"	126° 20' 12"	1115
	C11	48° 18' 57"	126° 26' 42"	1330
Estevan Point	G1	49° 20' 30"	126° 35' 00"	60
	G3	49° 15' 00"	126° 43' 42"	126
	G4	49° 11' 18"	126° 49' 24"	150
	G5	49° 07' 24"	126° 55' 18"	257
	G7	48° 59' 24"	127° 07' 12"	1800
Brooks Peninsula	BP1	50° 04' 48"	127° 52' 48"	32
	BP2	50° 04' 00"	127° 54' 12"	99
	BP3	50° 03' 12"	127° 55' 18"	139
	BP4	50° 04' 24"	127° 58' 06"	1090
	BP5	50° 00' 00"	128° 00' 00"	1230
	BP6	49° 56' 12"	128° 05' 30"	1730
	BP7	49° 52' 24"	128° 11' 12"	2200
Cape Scott	CS1	50° 34' 54"	129° 41' 30"	>2000
	CS3	50° 45' 36"	129° 20' 00"	200
	CS6	51° 00' 00"	128° 50' 00"	65
	CPE1	51° 00' 00"	127° 50' 00"	150
	CPE2	50° 43' 00"	128° 40' 00"	140

APPENDIX E

Table E.7 Location and water depth of stations occupied during May 1999 (Cruise ID#9911) off the west coast of Vancouver Island. Under the station column, B indicates La Pérouse Bank, C indicates Barkley Canyon, D indicates D Line, G indicates Estevan Point, J indicates J Line, BP indicates Brooks Peninula and CS indicates Cape Scott. See Figure 1.1 for location of transects.

Transect	**Station**	**Latitude** deg° min' sec" N	**Longitude** deg° min' sec" W	**Depth** (m)
La Pérouse Bank	C1	48° 50' 26"	125° 27' 44"	94
	B2	48° 39' 00"	125° 02' 24"	56
	B4	48° 35' 40"	125° 08' 43"	105
	B6	48° 32' 40"	125° 15' 31"	110
	B8	48° 25' 18"	125° 28' 39"	135
	B10	48° 18' 34"	125° 41' 21"	151
	B12	48° 12' 55"	125° 51' 54"	450
	B14	48° 08' 29"	126° 00' 00"	966
	B16	48° 00' 32"	126° 17' 00"	1530
Barkley Canyon	C2	48° 48' 41"	125° 30' 57"	111
	C4	48° 43' 28"	125° 40' 48"	166
	C7	48° 32' 58"	126° 00' 30"	129
	C8	48° 29' 27"	126° 07' 06"	201
	C9	48° 25' 24"	126° 13' 42"	659
	C11	48° 22' 24"	126° 20' 12"	1115
	C12	48° 18' 57"	126° 26' 42"	1330
D Line	D2	48° 58' 21"	125° 47' 03"	45
	D4	48° 53' 10"	125° 57' 00"	60
Estevan Point	G1	49° 20' 30"	126° 35' 00"	60
	G2	49° 18' 42"	126° 38' 06"	105
	G3	49° 15' 00"	126° 43' 42"	126
	G4	49° 11' 18"	126° 49' 24"	150
	G7	49° 07' 24"	126° 55' 18"	250
	G8	48° 51' 10"	127° 19' 21"	2081
J Line	J1	49° 44' 18"	127° 02' 30"	63
	J2	49° 42' 40"	126° 05' 18"	79
	J4	49° 35' 25"	126° 16' 46"	150
	J6	49° 27' 29 "	126° 28' 35"	1001
	J8	49° 20' 07 "	126° 40' 58"	> 2000
Brooks Peninsula	BP2	50° 04' 00"	127° 54' 12"	99
	BP4	50° 04' 24"	127° 58' 06"	1090
	BP6	49° 56' 12"	128° 05' 30"	730
	BP7	49° 52' 24"	128° 11' 12"	>2200
	BP8	49° 48' 36"	128° 16' 48"	>2200
Cape Scott	JI22	50° 39' 48"	129° 17' 36"	>2200
	CS1	50° 34' 54"	129° 41' 30"	>2200

APPENDIX E

Table E.8 Location and water depth of stations occupied during July 1999 (Cruise ID#9928) off the west coast of Vancouver Island. Under the station column, B indicates La Pérouse Bank, C indicates Barkley Canyon, G indicates Estevan Point and BP indicates Brooks Peninula. See Figure 1.1 for location of transects.

Transect	Station	Latitude deg° min' sec" N	Longitude deg° min' sec" W	Depth (m)
La Pérouse Bank	B6	48° 32' 40"	125° 15' 31"	110
	B8	48° 25' 18"	125° 28' 39"	135
	B16	48° 00' 32"	126° 17' 00"	1530
Barkley Canyon	C1	48° 50' 26"	125° 27' 44"	90
	C4	48° 43' 28"	125° 40' 48"	162
	C5	48° 39' 56"	125° 47' 24"	90
	C6	48° 36' 28"	125° 54' 00"	95
	C7	48° 32' 58"	126° 00' 30"	129
	C8	48° 29' 27"	126° 07' 06"	201
	C9	48° 25' 24"	126° 13' 42"	659
	C11	48° 22' 24"	126° 20' 12"	1115
Estevan Point	G1	49° 20' 30"	126° 35' 00"	60
	G2	49° 18' 42"	126° 38' 06"	105
	G3	49° 15' 00"	126° 43' 42"	126
	G6	49° 03' 30"	127° 07' 12"	866
	G7	49° 07' 24"	126° 55' 18"	250
Brooks Peninsula	BP2	50° 04' 00"	127° 54' 12"	99
	BP3	50° 03' 12"	127° 55' 18"	172
	BP4	50° 04' 24"	127° 58' 06"	1090
	BP6	49° 56' 12"	128° 05' 30"	1730
	BP7	49° 52' 24"	128° 11' 12"	2200

APPENDIX E

Table E.9 Location and water depth of stations occupied during October 1999 (Cruise ID#9935) off the west coast of Vancouver Island. Under the station column, B indicates La Pérouse Bank, C indicates Barkley Canyon, D indicates D Line, G indicates Estevan Point, J indicates J Line, BP indicates Brooks Peninula and CS indicates Cape Scott transect. See Figure 1.1 for location of transects.

Transect	Station	Latitude deg° min' sec" N	Longitude deg° min' sec" W	Depth (m)
La Pérouse Bank	C1	48° 28' 59"	125° 15' 14"	156
	B4	48° 35' 40"	125° 08' 43"	105
	B6	48° 32' 40"	125° 15' 31"	110
Barkley Canyon	C4	48° 43' 28"	125° 40' 48"	162
	C7	48° 32' 58"	126° 00' 30"	129
	C8	48° 29' 27"	126° 07' 06"	201
	C8	48° 25' 24"	126° 13' 42"	659
	C11	48° 18' 57"	126° 26' 42"	1330
Line D	D1	48° 49' 06"	125° 43" 48"	33
	D2	48° 58' 21"	125° 47' 03"	45
	D4	48° 53' 10"	125° 57' 00"	60
	D8	48° 39' 10"	126° 23' 24"	760
	D10	48° 32' 12"	126° 36' 36"	1475
Estevan Point	G1	49° 20' 30"	126° 35' 00"	60
	G3	49° 15' 00"	126° 43' 42"	126
	G7	48° 59' 24"	127° 07' 12"	1800
Line J	J6	49° 27' 29"	126° 28' 35"	1001
	J8	49° 20' 07"	126° 40' 58"	> 2000
Brooks Peninsula	BP2	50° 04' 00"	127° 54' 12"	99
	BP5	50° 00' 00"	128° 00' 00"	1230
	BP7	49° 52' 24"	128° 11' 12"	2200
Cape Scott	CS7	51° 04' 30"	128° 44' 00"	65
	CPE2	50° 43' 00"	128° 40' 00"	140
	CS3B	51° 00' 00"	129° 27' 00"	
	Q3	50° 39' 48"	129° 01' 54"	750

APPENDIX F

CONVERSION OF CELLS L^{-1} TO CARBON L^{-1}

For the analysis of the taxonomy data conversion from cell L^{-1} to carbon L^{-1} is necessary. The equations given by Strathman (1967) were used for all species and are listed below:

Log Carbon = (-0.422) + 0.758 (Log Volume)	Diatoms only
Log Carbon = (-0.460) + 0.866 (Log Volume)	Other than Diatoms

Cell volumes specific to each species were required for the conversion of cells L^{-1} to carbon. Cell volume calculated using measurements of representative cells and equations for simple geometric shapes: spheroids, cylinders, boxes, and cones were supplied by R. Haigh (unpubl. data). Collection of this information is a time consuming task and the author greatly appreciated the efforts of R. Haigh. Cell specific volumes for diatoms are listed in Tables F.1 and F.2 for other phytoplankton species.

Table F.1 Cell volume and carbon per cell of the diatom species observed off the west coast of Vancouver Island during 1997 and 1998. P indicates pennate diatoms and C indicates centric diatoms.

Diatom	**Type**	**Shape**	**Volume** ($10^3\ \mu m^3$)	**C/cell** ($10^{-4}\ \mu g$/cell)
Asterionella glacialis	P	Triangle box	1.92	1.17
Centric spp.	C	Cylinder	1.40	0.92
Chaetoceros compressus	C	Cylinder	1.53	0.98
Chaetoceros convolutus	C	Cylinder	5.20	2.48
Chaetoceros debilis	C	Cylinder	1.55	0.99
Chaetoceros eibenii	C	Cylinder	13.2	5.02
Chaetoceros radicans	C	Cylinder	0.67	0.52
Chaetoceros socialis	C	Cylinder	0.37	0.34
Chaetoceros socialis, spore	C	Cylinder	0.12	0.15
Chaetoceros spp.	C	Cylinder	1.87	1.14
Cylindrotheca closterium	C	Ellipsoid	0.26	0.26
Detonela pumila	C	Cylinder	9.19	3.82
Fragilaria spp.	P	Rect. Box	6.21	2.84
Leptocylindrus danicus	C	Cylinder	2.88	1.59
Leptocylindrus minimus	C	Cylinder	0.20	0.21
Navicula spp.	P	Cylinder	1.07	0.75
Nitzschia spp.	P	Cylinder	0.03	0.05
Pennates (> 50 μm)	P	Box	9.92	4.05
Pennates (25-50 μm)	P	Box	2.94	1.61
Pseudo-nitzschia delicatissima	P	Cylinder	0.29	0.28
Pseudo-nitzschia pungens	P	Cylinder	2.22	1.30
Pseudo-nitzschia spp.	P	Cylinder	0.14	0.16
Proboscia alata	C	Cylinder	10.9	4.35
Dactyliosolen fragilissimus	C	Cylinder	7.0	3.11
Rhizosolenia setigera	C	Cylinder	32.9	10.1
Rhizosolenia stolterfothii	C	Cylinder	2.77	1.54
Skeletonema costatum	P	Cylinder	0.60	0.48
Synedra spp.	P	Elliptic Cylinder	1.92	1.16
Thalassionema nitzschioides	P	Rect. box	0.99	0.70
Thalassiosira aestivalis	C	Cylinder	32.1	9.86
Thalassiosira spp. (< 5 μm)	C	Cylinder	0.03	0.05
Thalassiosira spp. (< 10 μm)	C	Cylinder	0.23	0.24
Thalassiosira spp.	C	Cylinder	0.77	0.58
Thalassiosira cotula	C	Cylinder	3.94	2.01
Thalassiosira nordenskioeldii	C	Cylinder	14.5	0.39
Thalassiosira rotula	C	Cylinder	16.8	6.05

Table F.2 Cell volume and carbon per cell for other phytoplankton species (except diatoms) observed off the west coast of Vancouver Island during 1997 and 1998. P indicates autotrophic and H indicates heterotrophic nutrition.

Species	**Type**	**Shape**	**Volume** (10^3 μm^3)	**C/cell** (10^{-4} μg/cell)
Dinoflagellates				
Alexandrium tamarense	P	Ellipsoid	26.4	23.4
Ceratium furca	P	Cone	96.3	71.8
Ceratium kofoidii	P	Ellipsoid	8.89	9.12
Dinophysis spp.	P	Ellipsoid	23.8	2.36
Alexandrium pseudogoniaulax	P	Ellipsoid	47.0	38.6
Gymnodinium auratum	P	Ellipsoid	1.56	2.02
Gymnodinium spp. Small	P	Ellipsoid	1.56	2.02
Gymnodinium spp.	P	Ellipsoid	26.3	23.3
Gyrodinium fusiforme	P	Cone	9.07	9.28
Gyrodinium spp. small	H	Ellipsoid	0.42	0.64
Gyrodinium spp. Avg.	H	Ellipsoid	17.0	16.0
Katodinium rotundatum	P	Ellipsoid	0.29	0.48
Prorocentrum balticum	P	Ellipsoid	0.68	0.99
Prorocentrum gracile	P	Ellipsoid	3.65	4.22
Protoperidinium rhomboidalis	H	Spherical	149	106
Protoperidinium spp.	H	Ellipsoid	6.53	6.97
Unidentified-autotroph	P	Ellipsoid	7.09	7.5
Unidentified-heterotroph	H	Ellipsoid	3.33	3.89
Nanoflagellates (2-20 μm)				
Choanoflagellate spp. (< 5 μm)	P	Ellipsoid	0.02	0.04
Choanoflagellate spp. (<10 μm)	P	Ellipsoid	0.04	0.09
Choanoflagellate spp.	P	Ellipsoid	0.03	0.07
Chrysochromulina spp. (< 5 μm)	P	Spheroid	0.03	0.06
Chrysochromulina spp. (avg)	P	Spheroid	0.24	0.41
Coccolithophores	P	Spheroid	0.06	0.13
Cryptomonad spp.	P	Ellipsoid	0.47	0.72
Dictyocha speculum-silicoflagellate	P	Spheroid	4.88	5.42
Flagellates, misc	P	Ellipsoid	0.01	0.03
Leucocryptos marina	P	Spheroid	0.91	1.26
Mantoniella squamata	P	Spheroid	0.01	0.02
Micromonas pusilla	P	Spheroid	0.002	0.01
Others				
Ciliates, misc	H	Ellipsoid	0.86	1.20
Hetersigma carterae	P	Ellipsoid	0.45	0.69
Mesodinium rubrum	P	Ellipsoid	9.35	9.52
Mesodinium rubrum, small	P	Ellipsoid	0.01	0.02

APPENDIX G

INCIDENT SURFACE IRRADIANCE DURING PRIMARY PRODUCTIVITY MEASUREMENTS

The incident surface solar irradiance during primary productivity measurements presented in Chapter 2 is shown in Figures G1-G.6. Data are not available for October 1998 due to a datalogger malfunction. During April 1997 (Figure G.1) primary productivity incubation length was 24 hours. For the rest of the study period, primary productivity incubation length was 6 hours and the incubation period is indicated by the shaded region in each plot.

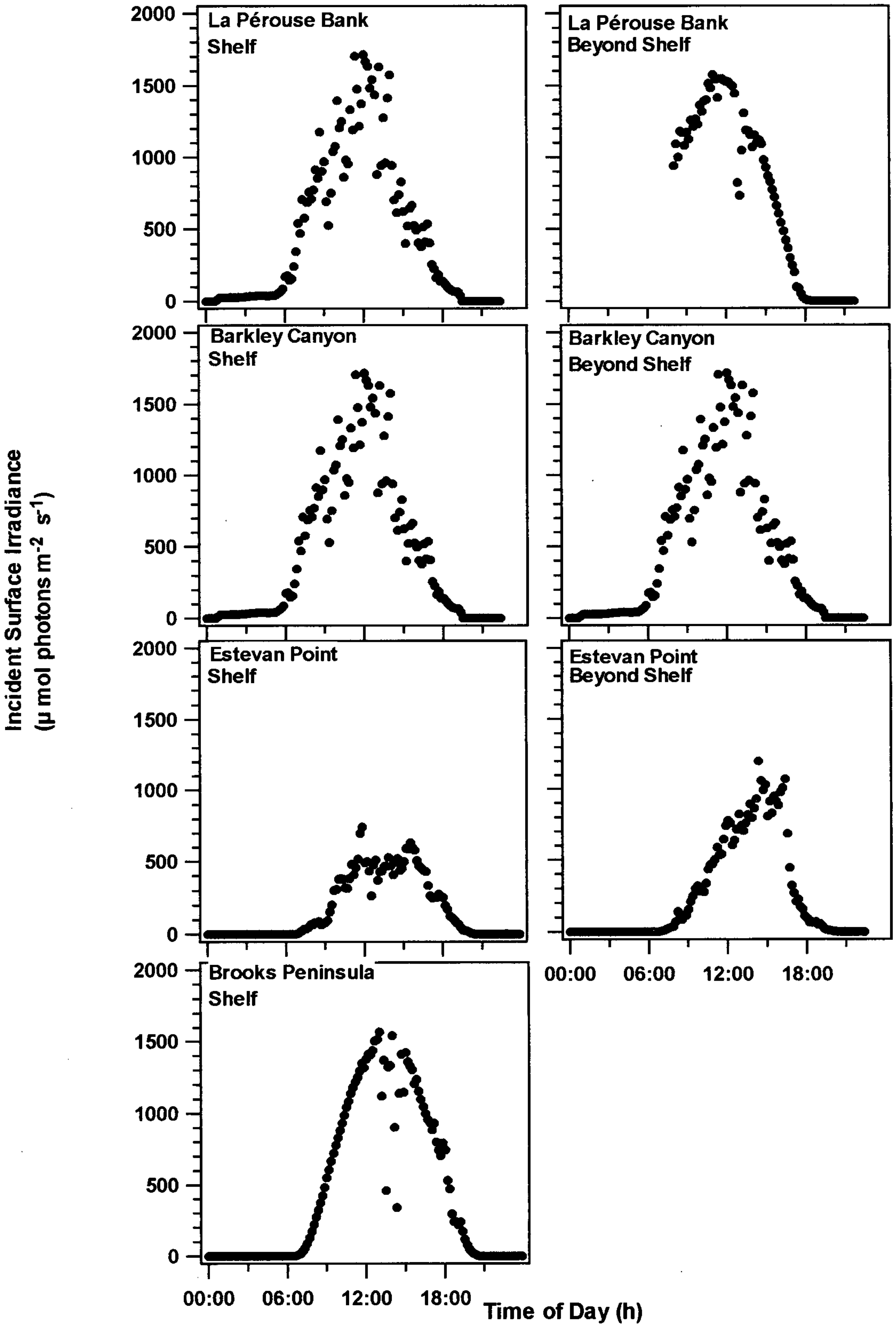

Figure G.1 Incident surface irradiance for primary productivity measurements during April 1997 off the west coast of Vancouver Island. Incubation period was 24 hours. Primary productivity was not measured at the beyond shelf station of the Brooks Peninsula transect. See Figure 2.1 for location of transects.

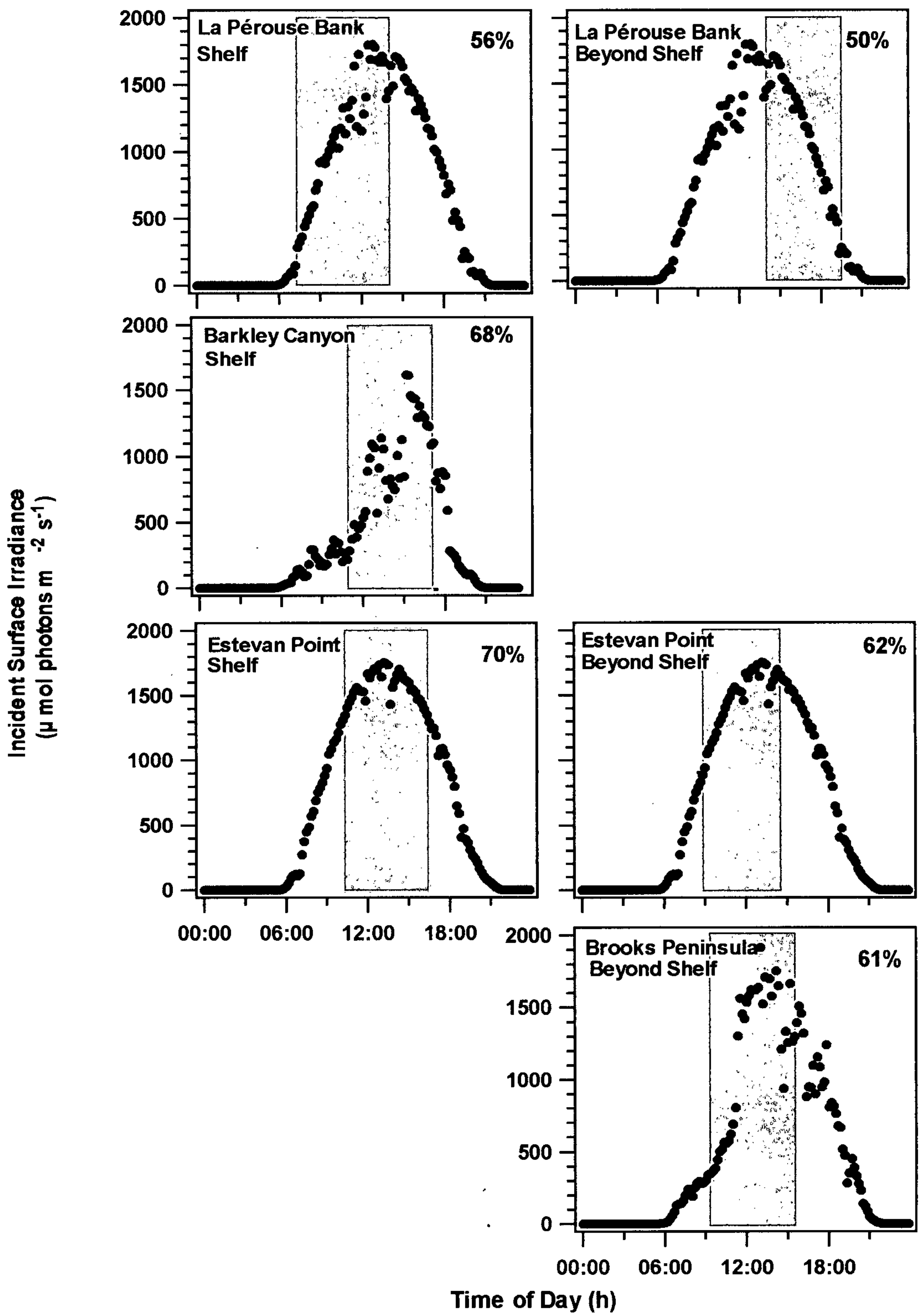

Figure G.2 Incident surface irradiance during primary productivity measurements in July 1997 off the west coast of Vancouver Island. The shaded region demarcates the incubation period. Primary productivity was not measured at the shelf station of the Brooks Peninsula transect or the beyond shelf station of the Barkley Canyon transect. Number in the right hand corner of each plot is the percentage that the incubation period represented of the total daily irradiance. See Figure 2.1 for location of transects.

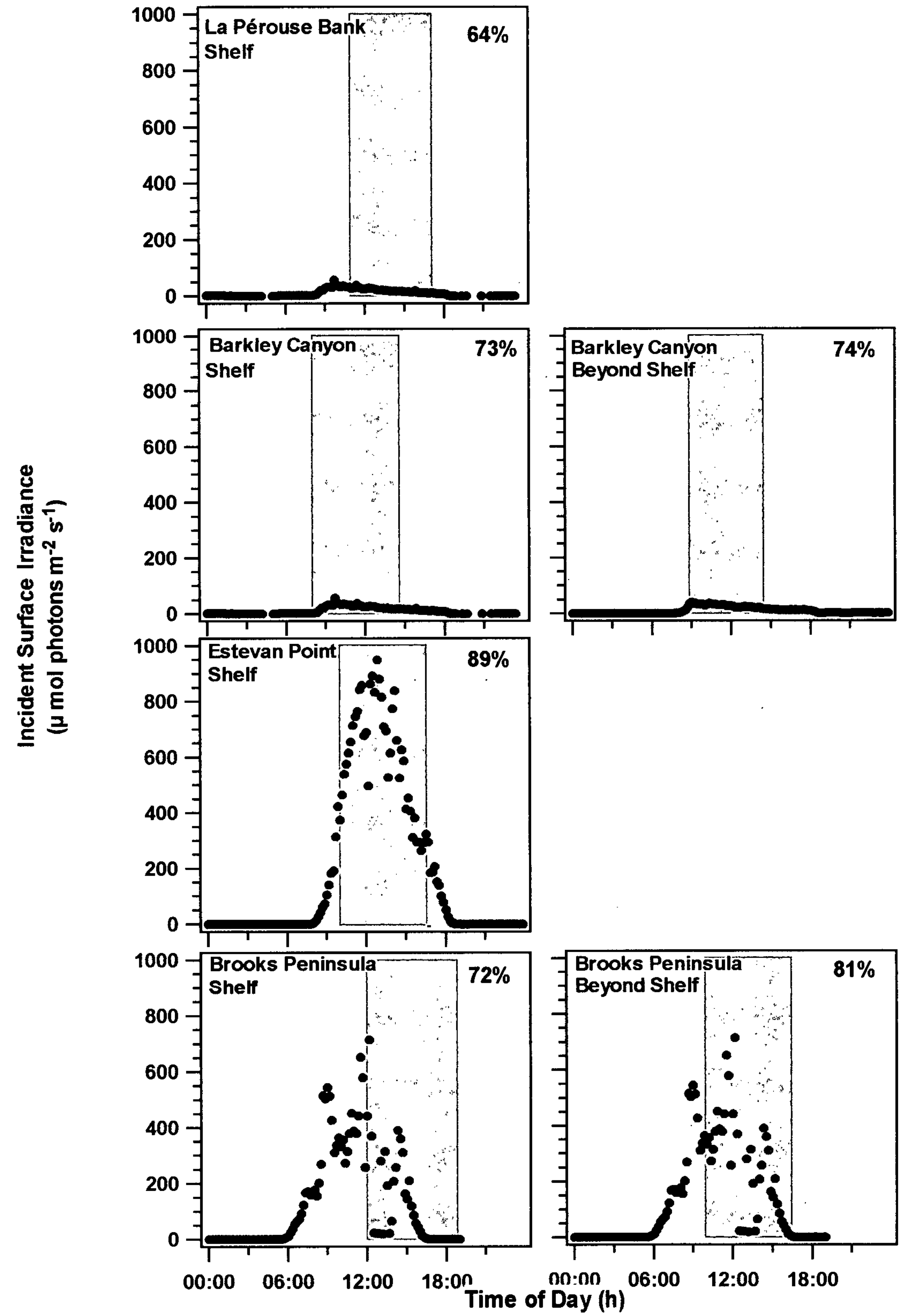

Figure G.3 Incident surface irradiance during primary productivity measurements in October 1997 off the west coast of Vancouver Island. The shaded region demarcates the incubation period. Primary productivity was not measured in the beyond shelf region of the Estevan Point and La Pérouse Bank transects. Number in right hand corner of each plot is the percentage that the incubation period represented of the total daily irradiance. Note scale change relative to Figure G.1 and G.2. See Figure 2.1 for location of transects.

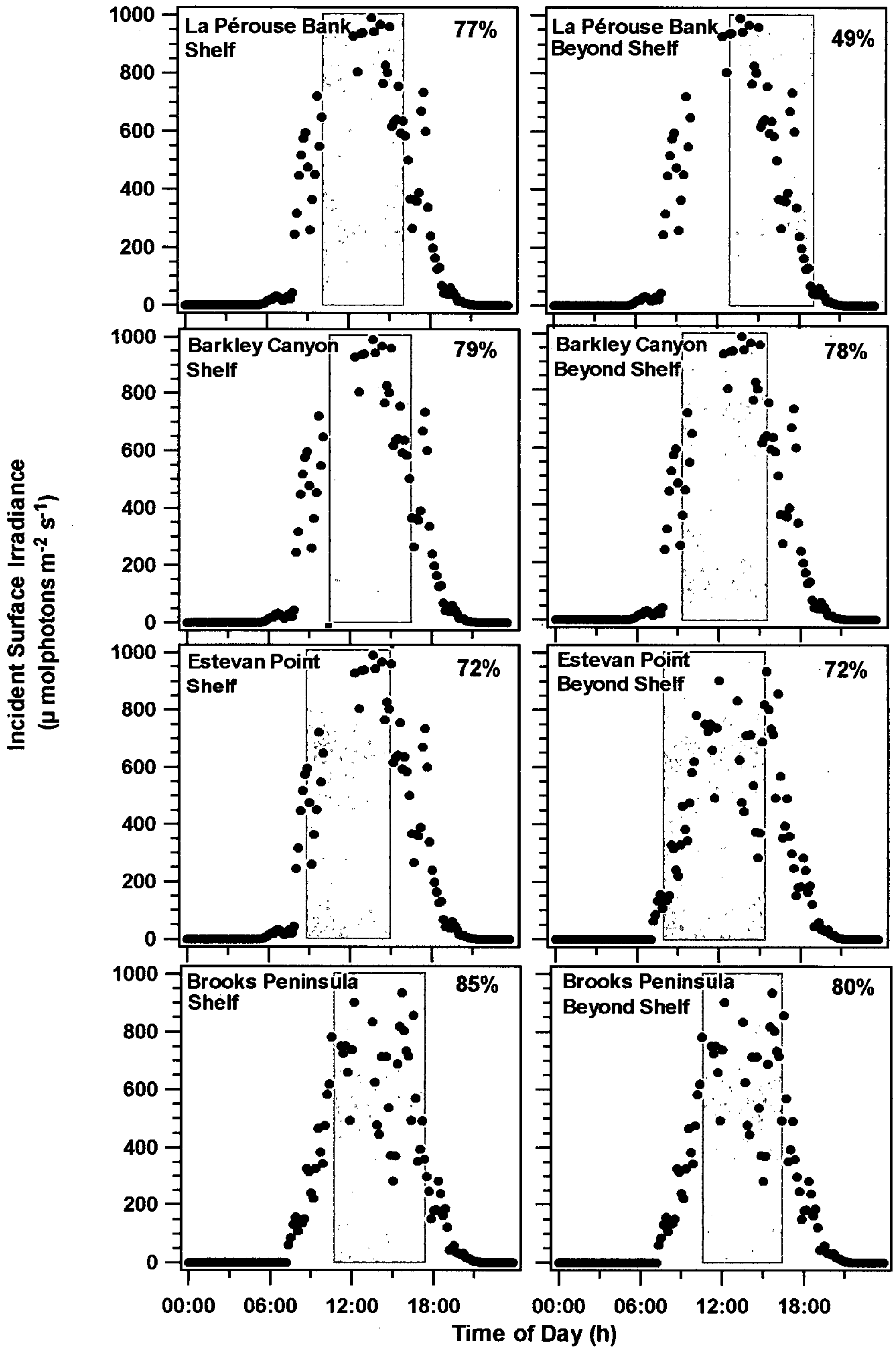

Figure G.4 Incident surface irradiance during primary productivity measurements in May 1998 off the west coast of Vancouver Island. The shaded region demarcates the incubation period. Number in the right hand corner of each plot is the percentage that the incubation period represented of the total daily irradiance. See Figure 2.1 for location of transects.

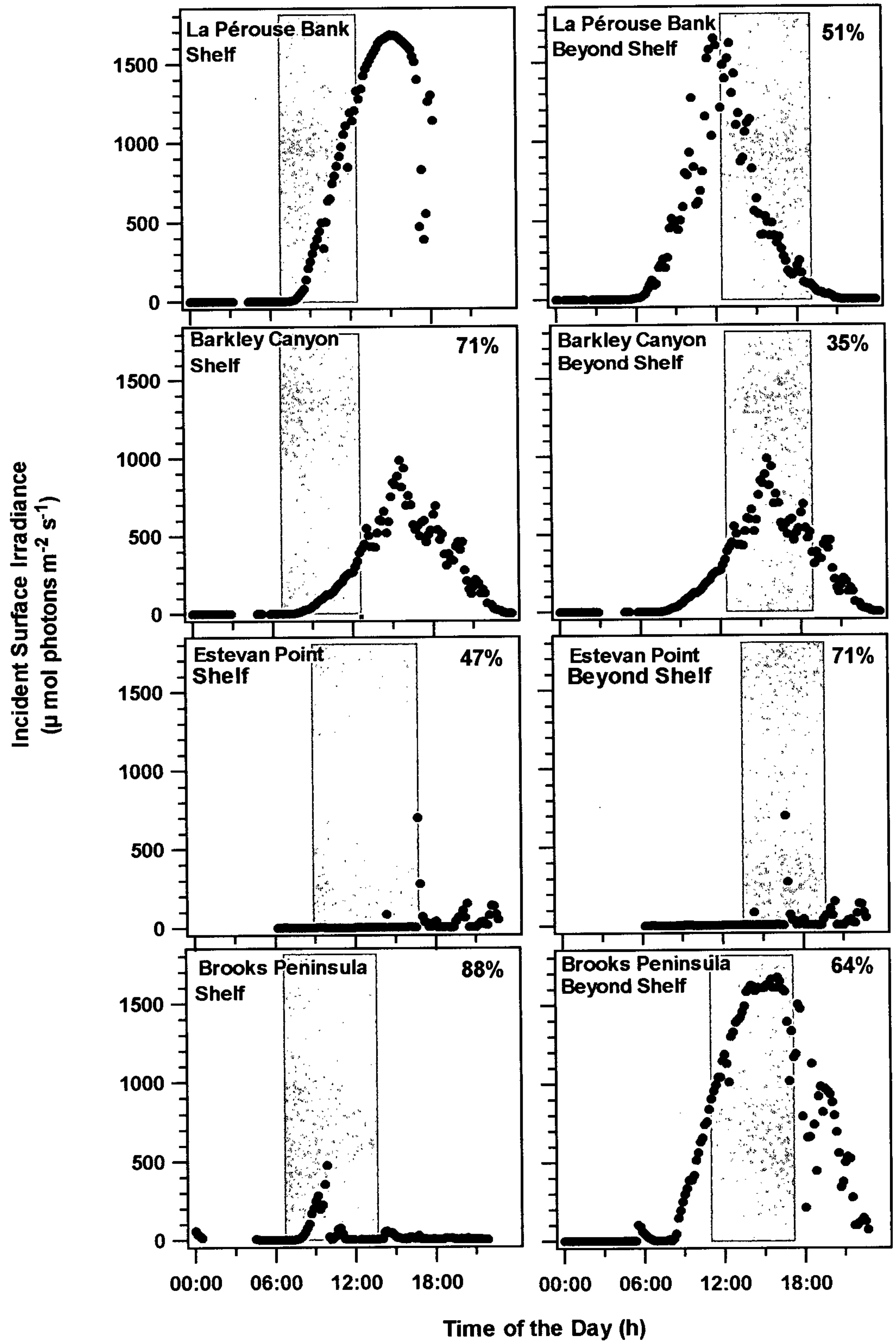

Figure C.5 Incident surface irradiance during primary productivity measurements during July 1998 off the west coast of Vancouver Island. The shaded region demarcates the incubation period. Number in the right hand corner of each plot is the percentage that the light during the incubation period represented of the total daily irradiance. See Figure 2.1 for location of transects.

APPENDIX H

VERTICAL PROFILES OF TEMPERATURE, SALINITY AND σ_T

Vertical profiles of temperature, salinity, and σ_t for the upper 200 m at a shelf and a beyond shelf station of each transect of La Pérouse Bank, Barkley Canyon, Estevan Point and Brooks Peninsula are presented for April 1997 (Figure H.1), July 1997 (Figure H.2), October 1997 (Figure H.3), May 1998 (Figure H.4), July 1998 (Figure H.5) and October 1998 (Figure H.6). The cruise dates when these profiles were measured are specified in Table A.1. For the deep stations, data set only shown for 0-200 m.

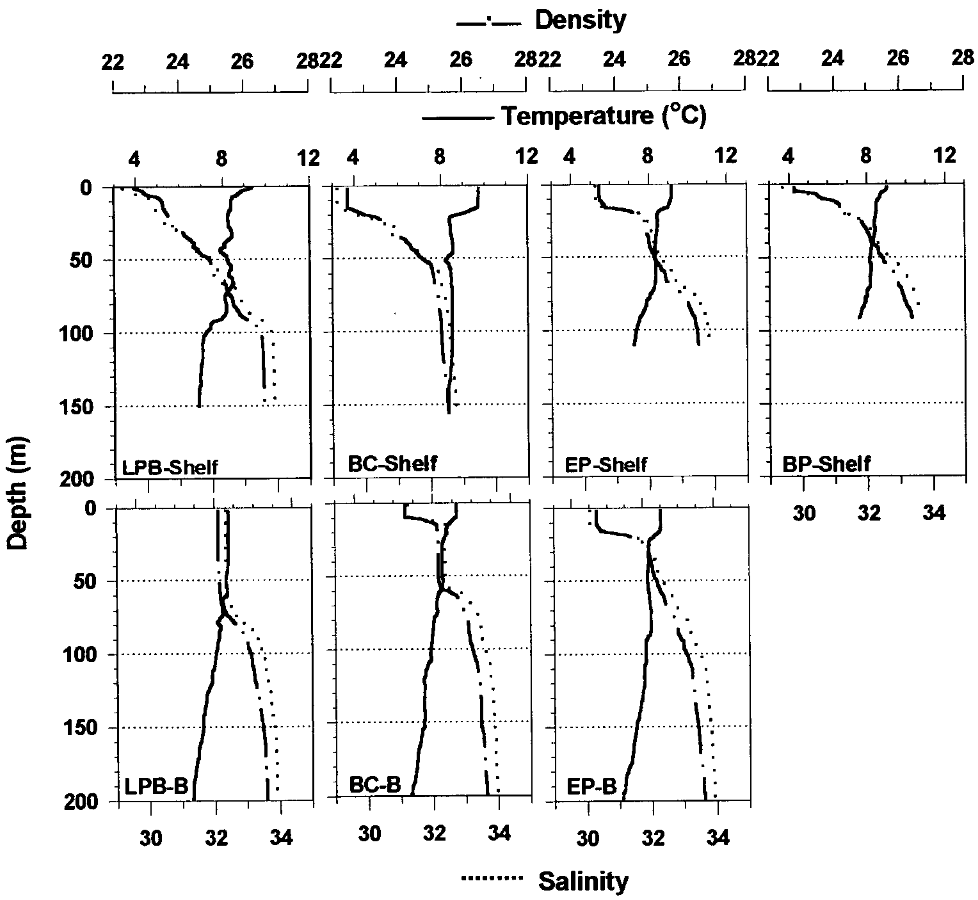

Figure H.1 Vertical profiles of density, salinity and temperature in April 1997 at a shelf and beyond shelf station along La Pérouse Bank (LPB), Barkley Canyon (BC), Estevan Point (EP) and Brooks Peninsula (BP) off the west coast of Vancouver Island. Data for deep stations only shown for 0 - 200 m depth. See Figure 1.1 for location of transects. Data not available for beyond shelf station on the Brooks Peninsula transect. B indicates beyond shelf region.

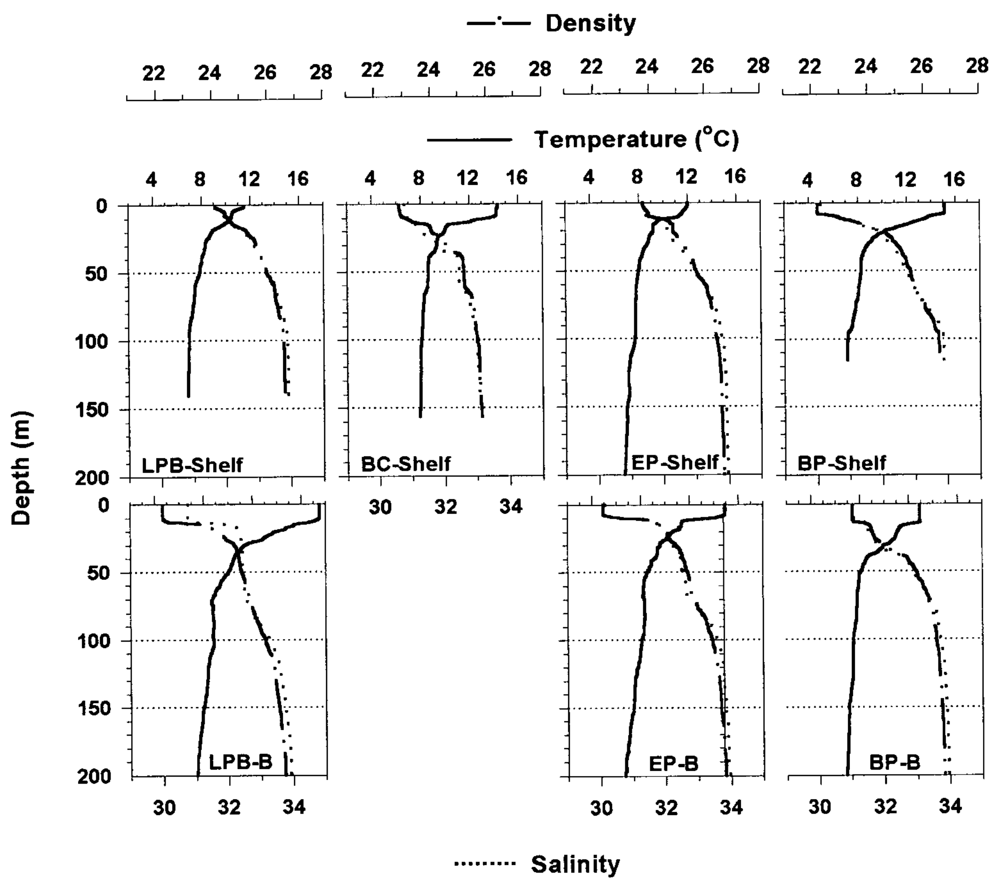

Figure H.2 Vertical profiles of density, salinity and temperature in July 1997 at a shelf and beyond shelf station along La Pérouse Bank (LPB), Barkley Canyon (BC), Estevan Point (EP) and Brooks Peninsula (BP) off the west coast of Vancouver Island. Data set for deep stations only shown for 0-200 m depth. Data set not available for beyond shelf station on the Barkley Canyon transect. See Figure 1.1 for location of transects. B indicates beyond shelf region.

2D Graph 1 2D Graph 1

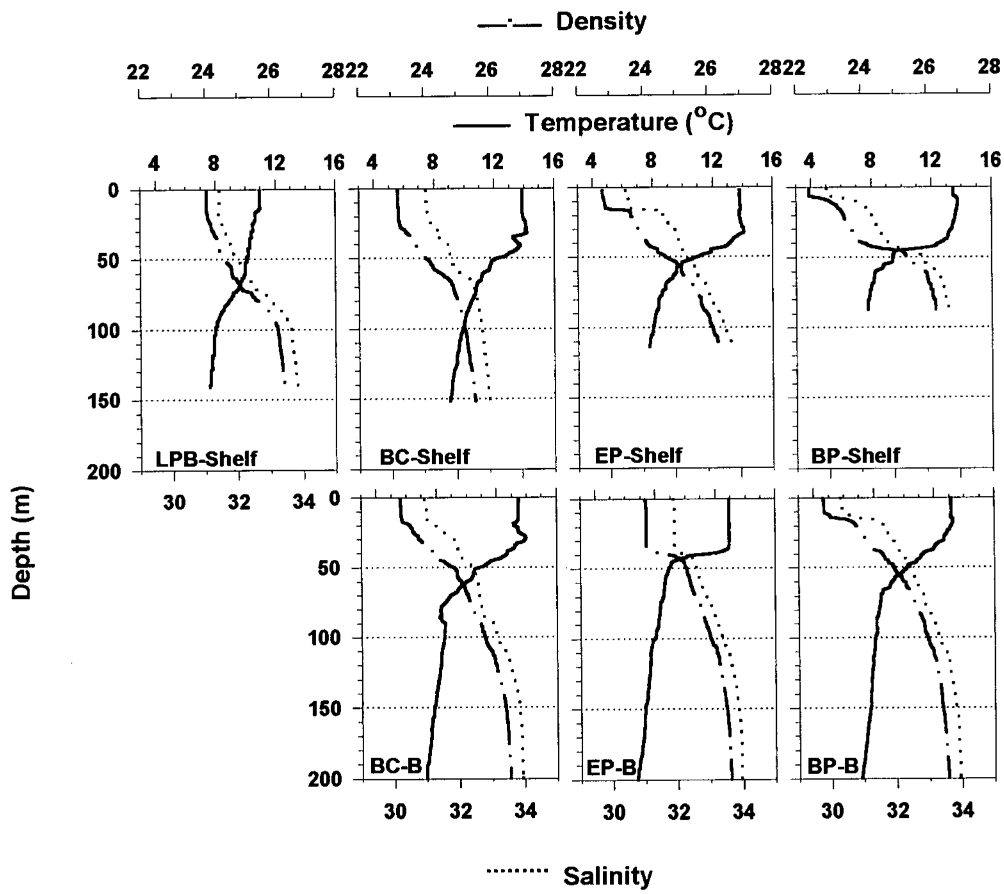

Figure H.3 Vertical profiles of density, salinity and temperature in October 1997 at a shelf and a beyond shelf station along La Pérouse Bank (LPB), Barkley Canyon (BC), Esteven Point (EP) and Brooks Peninsula (BP) off the west coast of Vancouver Island. Data for deep stations only shown for 0-200 m depth. See Figure 1.1 for location of transects. Data not available for the beyond shelf station of the La Pérouse Bank transect. B indicates beyond shelf region.

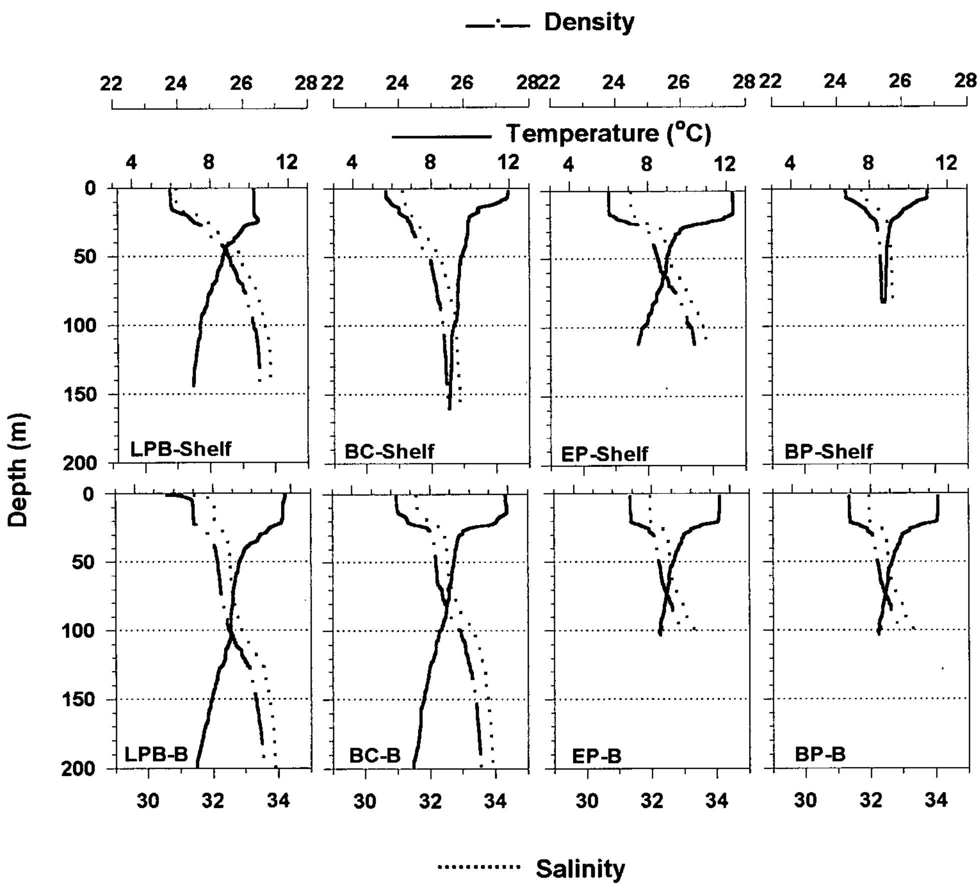

Figure H.4 Vertical profiles of density, salinity and temperature in May 1998 at a shelf and a beyond shelf station along La Pérouse Bank (LPB), Barkley Canyon (BC), Estevan Point (EP) and Brooks Peninsula (BP) off the west coast of Vancouver Island. Data for deep stations only shown for 0-200 m. Beyond shelf stations for the Estevan Point and Brooks Peninsula transect only sampled to 100 m depth. See Figure 1.1 for location of transects. B indicates beyond shelf region.

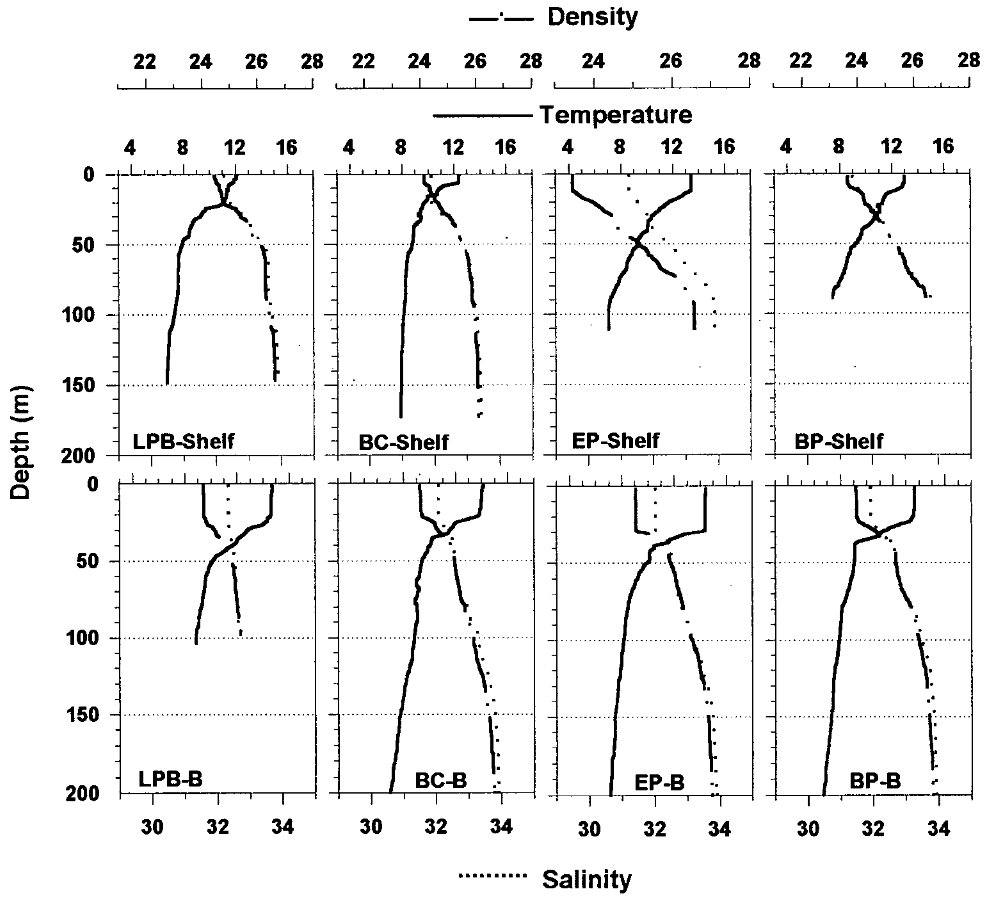

Figure H.5 Vertical profiles of density, salinity and temperature in July 1998 at a shelf and beyond shelf station along La Pérouse Bank (LPB), Barkley Canyon (BC), Estevan Point (EP), and Brook Peninsula (BP) off the west coast of Vancouver Island. Data for deep stations shown for 0-200 m depth. The beyond shelf station of La Pérouse Bank was only sampled to 100 m depth. See Figure 1.1 for location of transects. B indicates beyond shelf region.

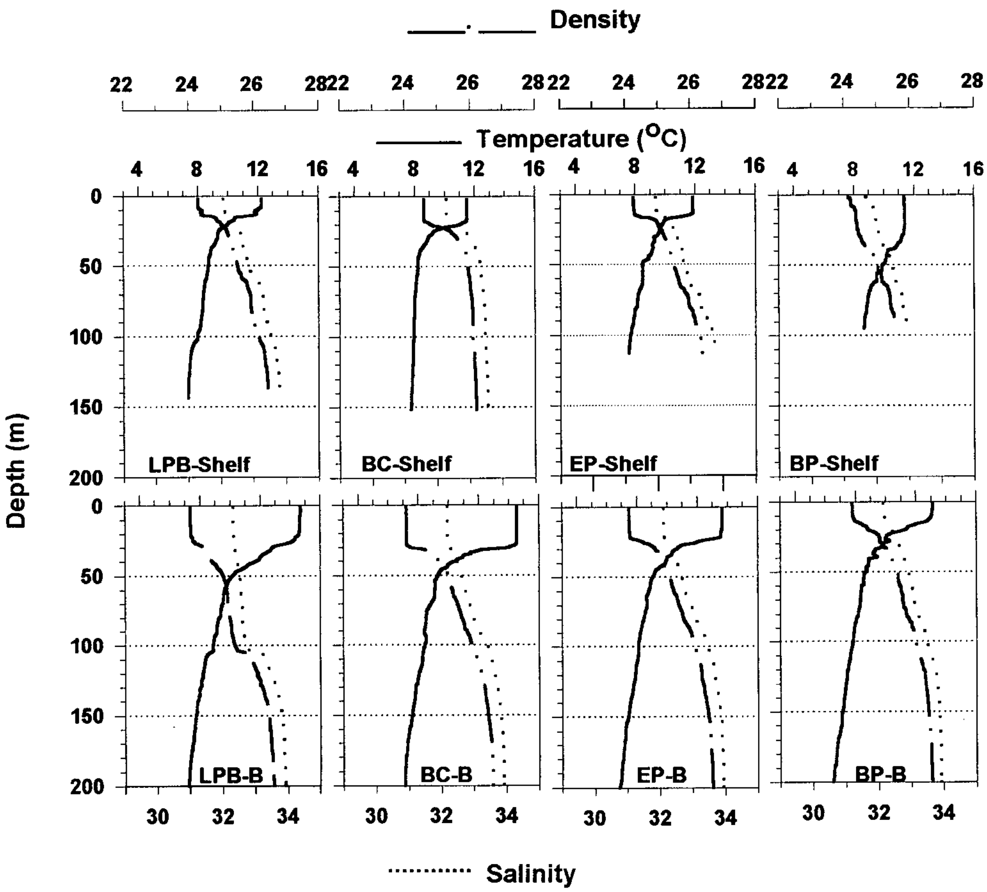

Figure H.6 Vertical profiles of density, salinity and temperature in October 1998 at a shelf and a beyond shelf station along La Pérouse Bank (LPB), Barkley Canyon (BC), Estevan Point (EP) and Brooks Peninsula (BP) on the west coast of Vancouver Island. Data set for deep stations shown for 0-200 m depth. See Figure 1.1 for location of transects. B indicates beyond shelf region.

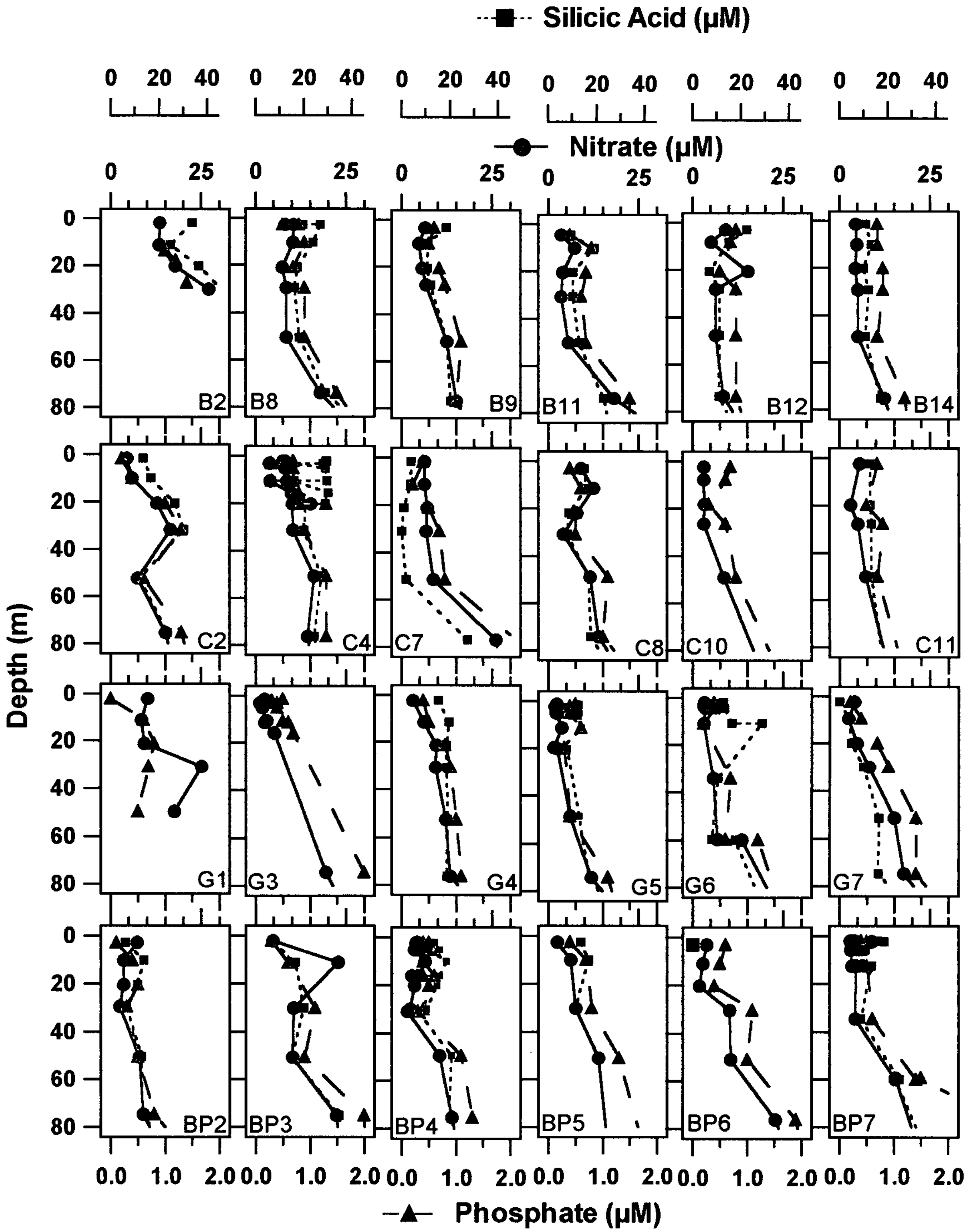

Figure I.1 Vertical profiles of nitrate, phosphate and silicic acid (µM) in April 1997 at all stations along transects of La Pérouse Bank (Line B), Barkley Canyon (Line C), Estevan Point (Line G) and Brooks Peninsula (Line BP) off the west coast of Vancouver Island. Station name is located at bottom of each graph.

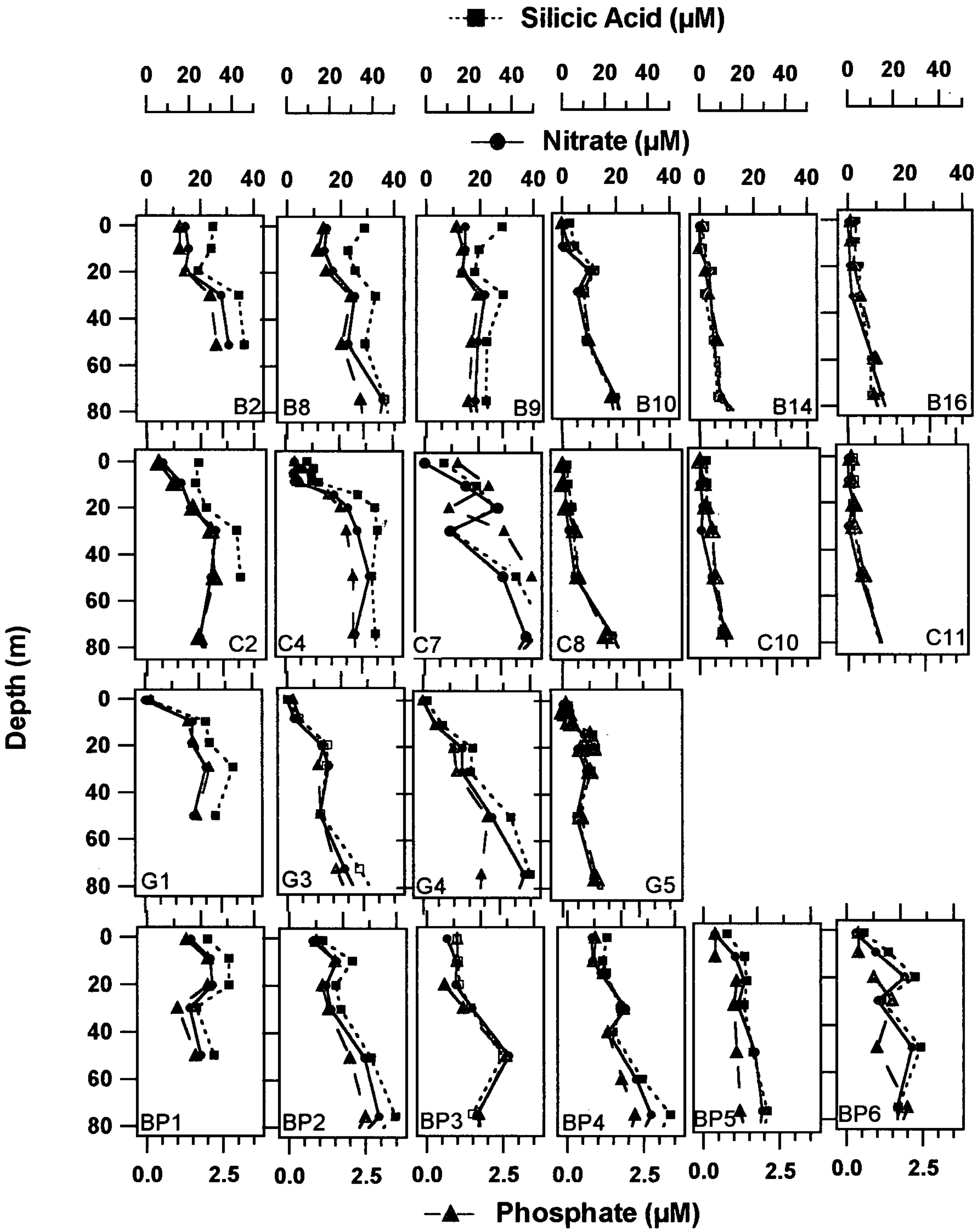

Figure I.2 Vertical profiles of nitrate, phosphate, and silicic acid (µM) in July 1997 at all stations along transects of La Pérouse Bank (Line B), Barkley Canyon, (Line C), Estevan Point (Line G), and Brooks Peninsula (Line BP) on the west coast of Vancouver Island. Station name is located at the bottom of each graph.

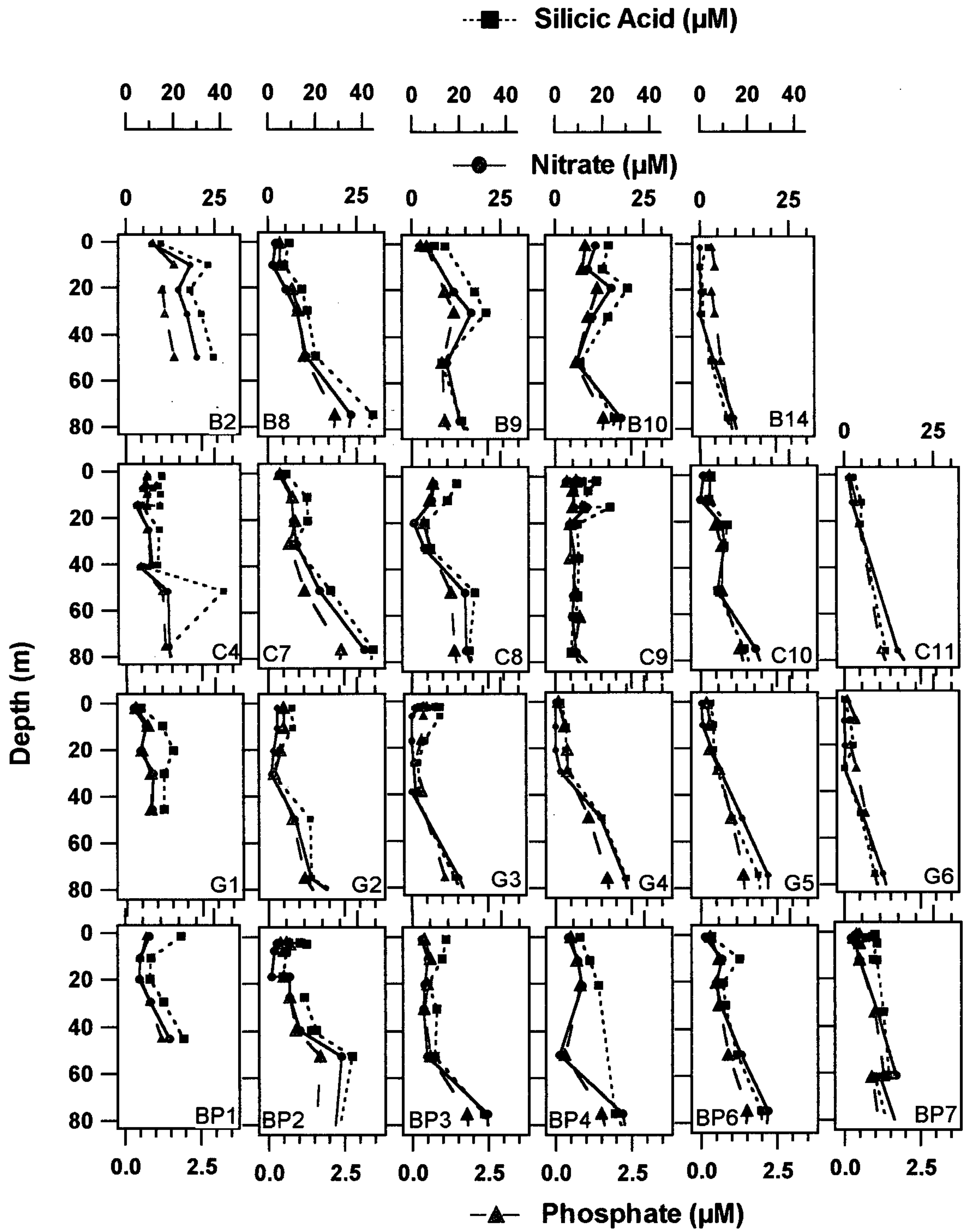

Figure I.3 Vertical profiles of nitrate, phosphate and silicic acid (µM) in October 1997 at all stations along transects of La Pérouse Bank (Line B), Barkley Canyon (Line C), Estevan Point (Line G) and Brooks Peninsula (Line BP) on the west coast of Vancouver Island. Station name is located at the bottom of each graph.

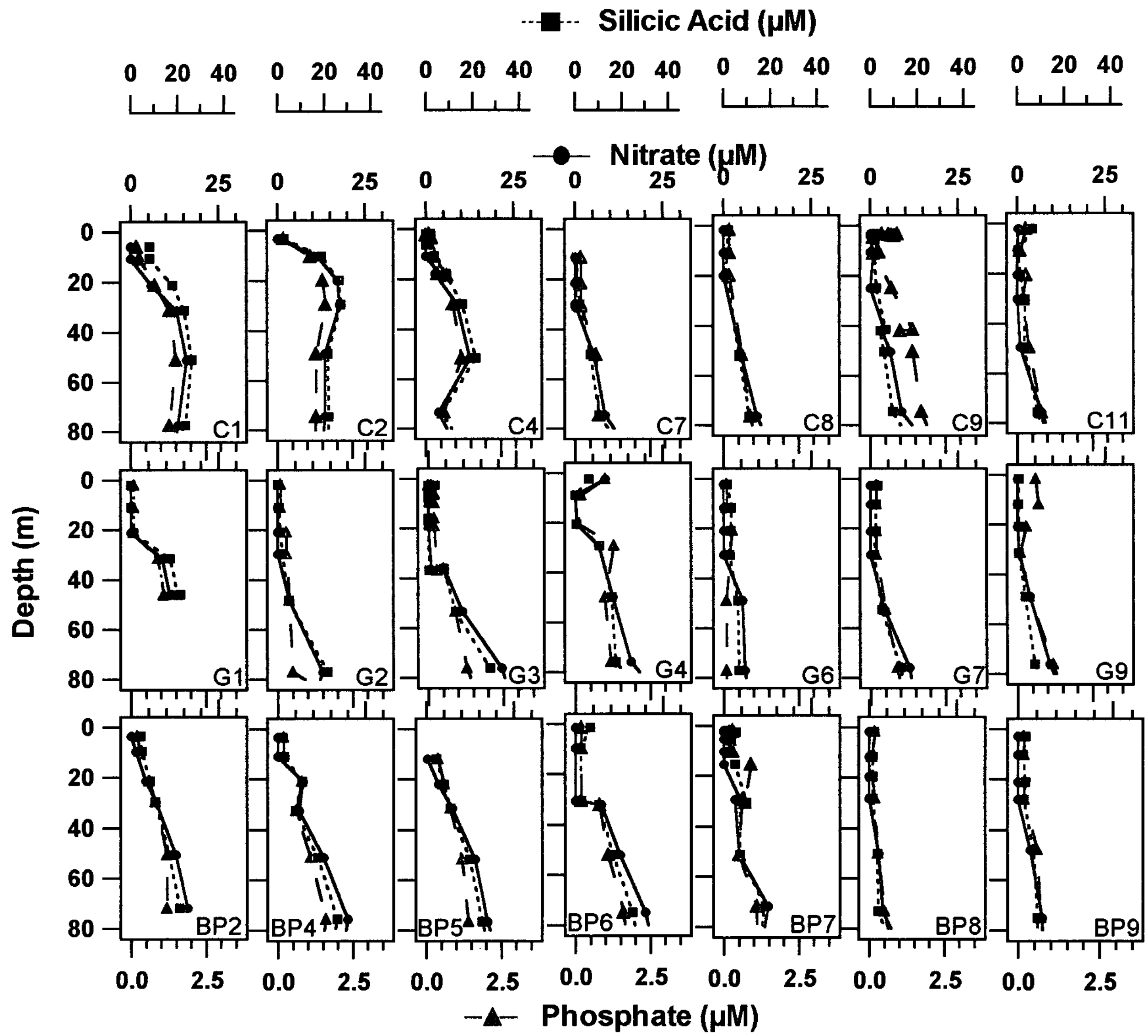

Figure I.4 Vertical profiles of nitrate, phosphate and silicic acid (µM) in May 1998 at all stations along transects of Barkley Canyon (Line C), Estevan Point (Line G) and Brooks Peninsula (Line BP) off the west coast of Vancouver Island. Station name is located at the bottom of each graph. No are data available for the La Pérouse Bank transect.

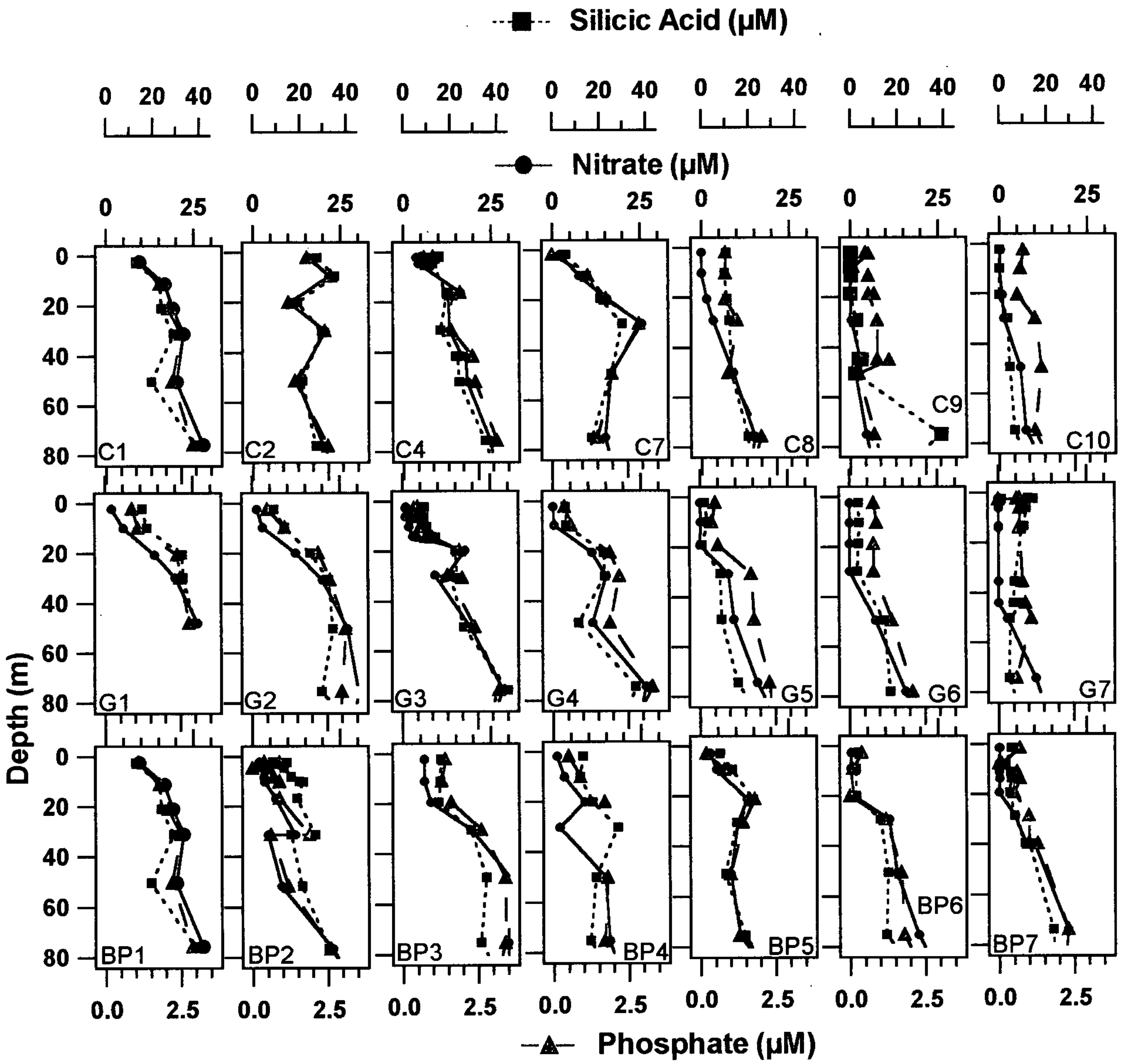

Figure I.5 Vertical profiles of nitrate, phosphate and silicic acid (µM) in July 1998 at all stations along transects of Barkley Canyon (Line C), Estevan Point (Line G) and Brooks Peninsula (Line BP) off the west coast of Vancouver Island. Station name is located at the bottom of each graph. No data are available for the La Pérouse Bank transect.

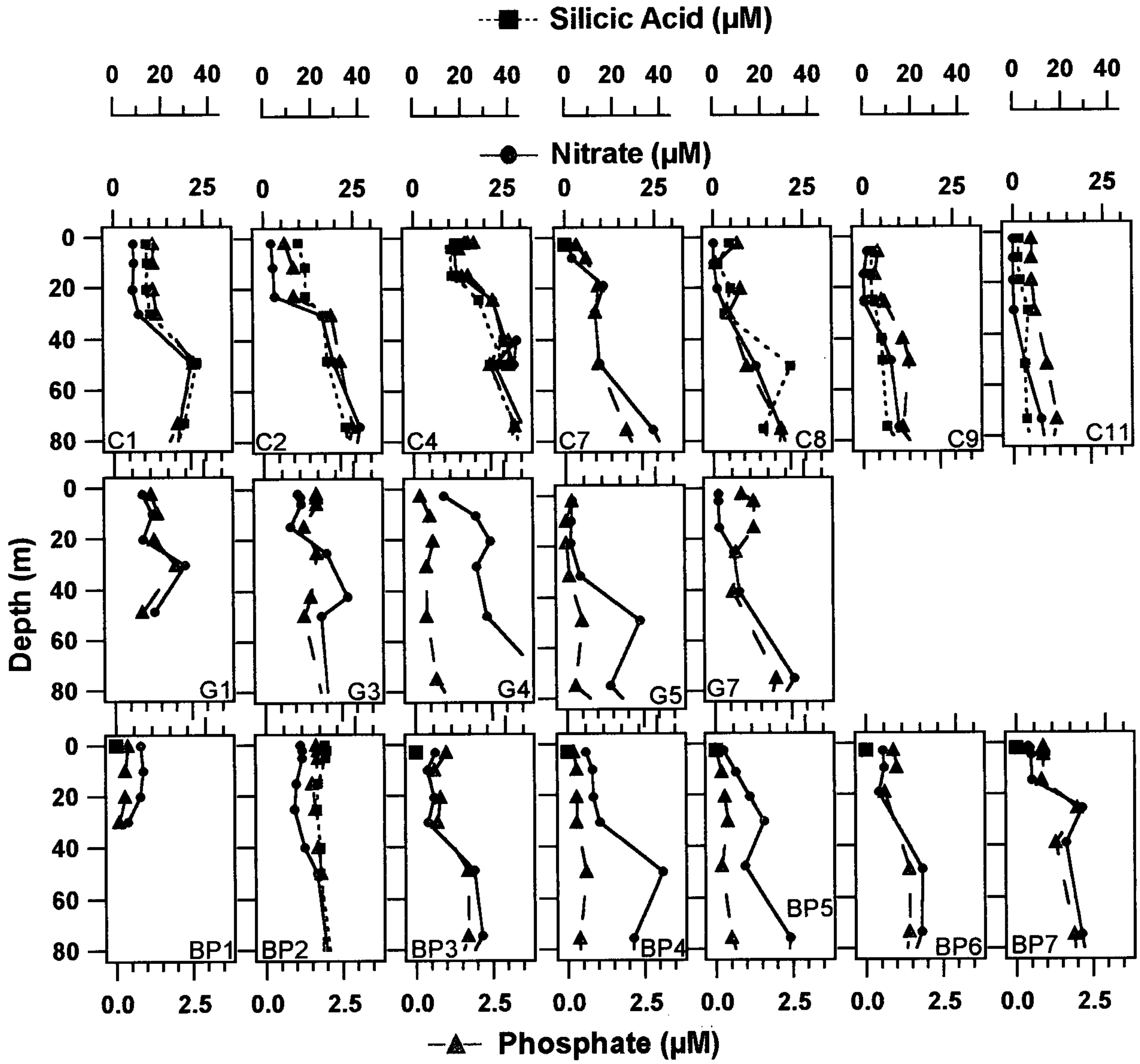

Figure I.6 Vertical profiles of nitrate, phosphate and silicic acid (µM) in October 1998 at all stations along transects of Barkley Canyon (Line C), Estevan Point (Line G) and Brooks Peninsula (Line BP) on the west coast of Vancouver Island. Station name is located at the bottom of each graph. No data are available for the La Pérouse Bank transect.

Table J.1 Size-fractionated chlorophyll (surface to 1% light depth ±1 SD) and the relative contribution of the >5µm fraction to total chlorophyll for: the west coast of Vancouver Island, the shelf regions and the beyond shelf regions off the west coast of Vancouver Island during 1997 and 1998. Means for the 1997, 1998 and all cruises are given along with the minimum and the maximum.

	West Coast of Vancouver Island			**Shelf Regions**			**Beyond Shelf Regions**		
	Chl *a* <5.0 µm mg m^{-2}	**Chl *a* >5.0 µm** mg m^{-2}	**Chl % >5.0 µm**	**Chl *a* <5.0 µm** mg m^{-2}	**Chl *a* >5.0 µm** mg m^{-2}	**Chl *a* % >5.0 µm**	**Chl *a* <5.0 µm** mg m^{-2}	**Chl *a* >5.0 µm** mg m^{-2}	**Chl *a* % >5.0 µm**
April 1997	32.3 ±14.7	29.8 ±47.3	48.0 ±40	25.8 ±21.8	56.2 ±62.0	69 ±48	38.9 ±1.8	3.5 ±1.2	8 ±2
	n=4	n=4	n=4	n=2	n=2	n=2	n=2	n=2	n=2
July 1997	32.2 ±16.3	41.1 ±46.5	44.0 ±23	36.7 ±21.3	73.0 ±48.3	67 ±18	27.6 ±12.2	9.1 ±3.2	25 ±3
	n=6	n=6	n=6	n=3	n=3	n=3	n=3	n=3	n=3
Oct. 1997	40.2 ±27.7	21.0 ±8.0	29.0 ±13	31.8 ±21.5	18.6 ±8.3	38.0 ±13	48.5 ±45.7	23.4 ±9.3	39 ±17
	n=6	n=6	n=6	n=4	n=4	n=4	n=2	n=2	n=2
1997 cruises	34.9 ±19.9	30.6 ±35.7	41 ±24	31.4 ±5.5	49.2 ±27.9	58 ±17	38.3 ±10.5	12.0 ±10.3	24 ±15
May 1998	30.6 ±22.4	27.6 ±26.1	41.0 ±21	38.0 ±26.4	44.4 ±25.5	55 ±18.0	23.1 ±17.9	10.9 ±13.6	27 ±11
	n=8	n=8	n=8	n=4	n=4	n=4	n=4	n=4	n=4
July 1998	27.6 ±14.8	84.9 ±83.4	61.3 ±24	36.9 ±15.5	150.3 ±67.5	77 ±13	18.2 ±6.5	19.6 ±17.4	45 ±21
	n=8	n=8	n=8	n=4	n=4	n=4	n=4	n=4	n=4
Oct. 1998	23.2 ±7.4	34.3 ±38.3	48.0 ±24	21.8 ±8.3	59.6 ±41.2	69 ±14	24.6 ±7.4	8.9 ±2.9	27 ±7
	n=8	n=8	n=8	n=4	n=4	n=4	n=4	n=4	n=4
1998 cruises	27.1 ±15.7	48.9 ±58.8	50 ±24	32.2 ±9.0	84.8 ±57.3	67 ±11	22.0 ±3.3	13.1 ±5.69	33 ±10
All cruises	31.0 ±17.6	39.8 ±51.1	46 ±24	31.8 ±6.7	67.0 ±44.7	62 ±14	31.1 ±11.3	12.6 ±7.4	29 ±13
	n=40	n=40	n=40	n=21	n=21	n=21	n=19	n=19	n=19
Minimum	8.7	1.8	5	10.4	7.5	23	8.7	1.8	5
Maximum	80.8	213.1	82	73.9	213.1	82	80.8	44.5	71

APPENDIX K

VERTICAL PROFILES OF SIZE-FRACTIONATED CHLOROPHYLL

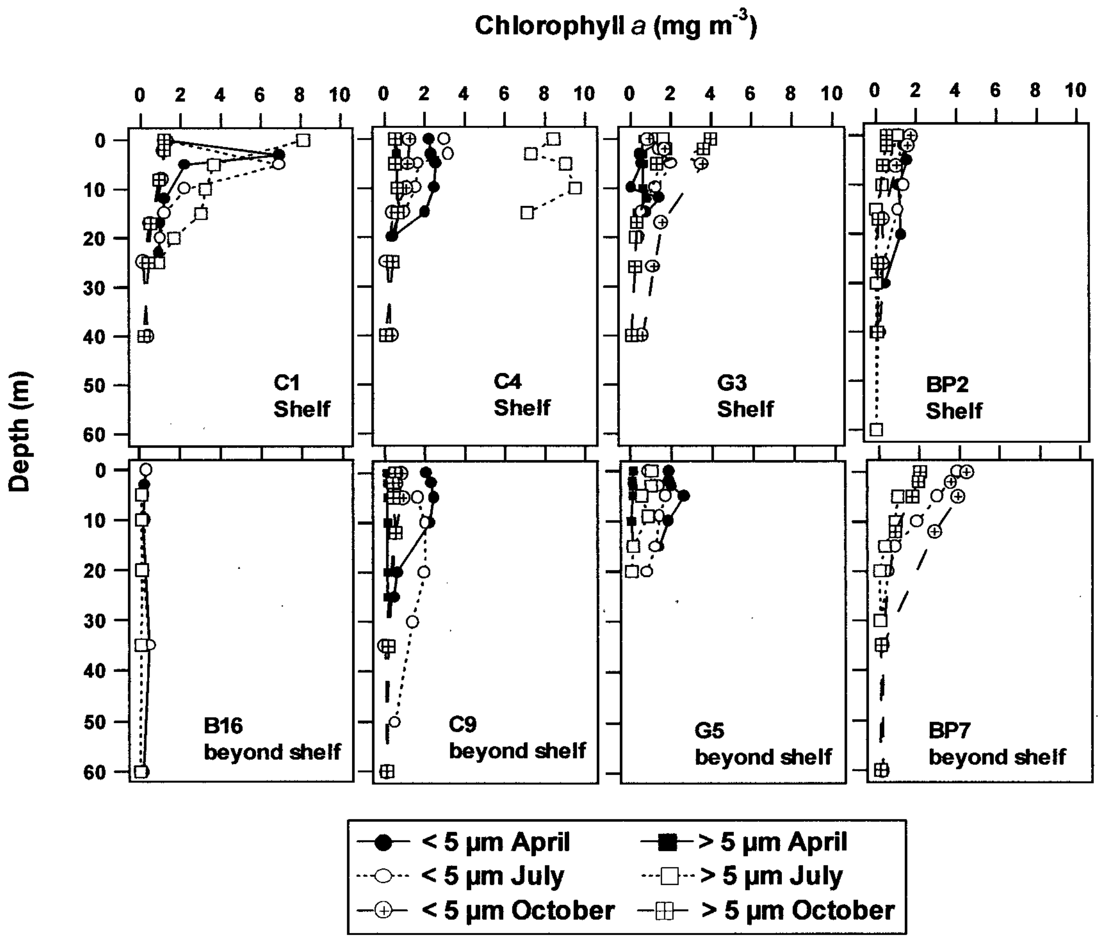

Figure K.1 Vertical profiles of size-fractionated chlorophyll *a* for April, July, and October 1997 at shelf and beyond shelf stations along transects of La Pérouse Bank (Line B), Barkley Canyon (Line C), Estevan Point (Line G) and Brooks Peninsula (Line BP) off the west coast of Vancouver Island. Data are not available for the > 5.0 µm fraction for station C1, BP2, B16 and BP7. Samples taken down to 1% surface irradiation. See Figure 2.1 for location of stations.

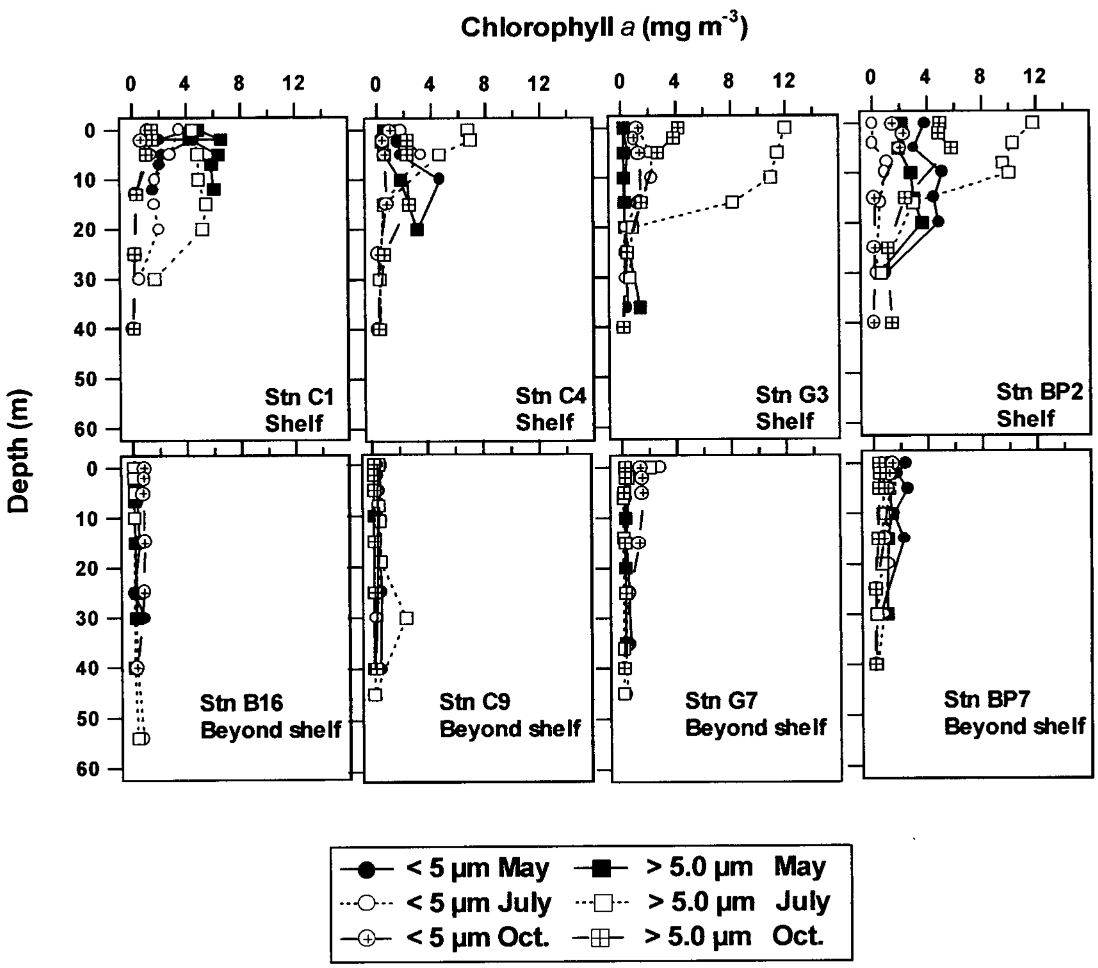

Figure K.2 Vertical profiles of size-fractionated chlorophyll *a* May, July, and October 1998 at shelf and beyond shelf stations along transects of La Pérouse Bank (Line B), Barkley Canyon (Line C), Estevan Point (Line G) and Brooks Peninsula (Line BP) off the west coast of Vancouver Island. Samples taken down to 1% light depth. See Figure 2.1 for location of stations.

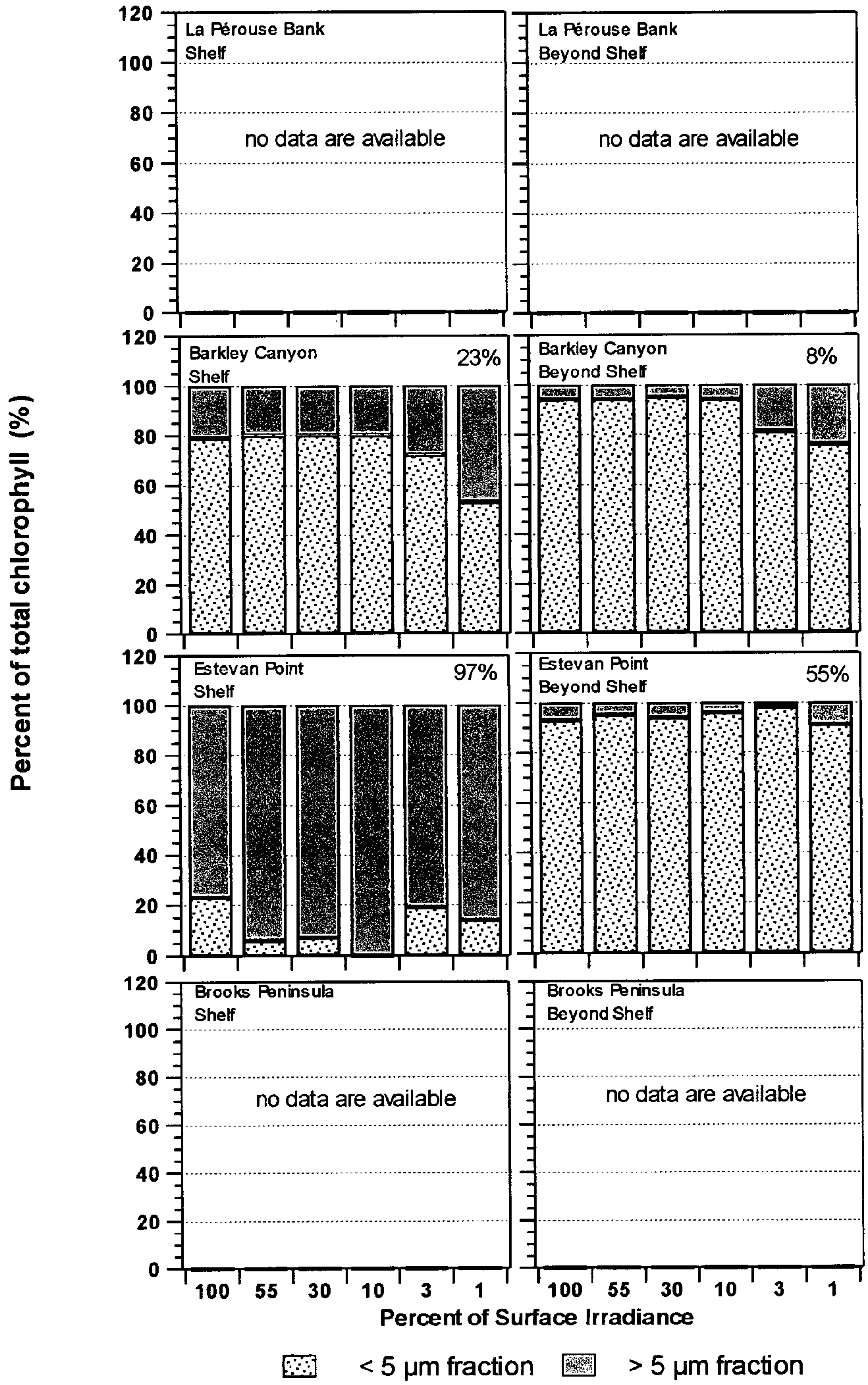

Figure L.1 Relative contribution of <5 μm size fraction and >5 μm size fraction to chlorophyll at each light depth for the shelf and the beyond shelf station of each transect during April 1997. The relative contribution of > 5 μm fraction to depth integrated chlorophyll is given in top right hand corner of each plot.

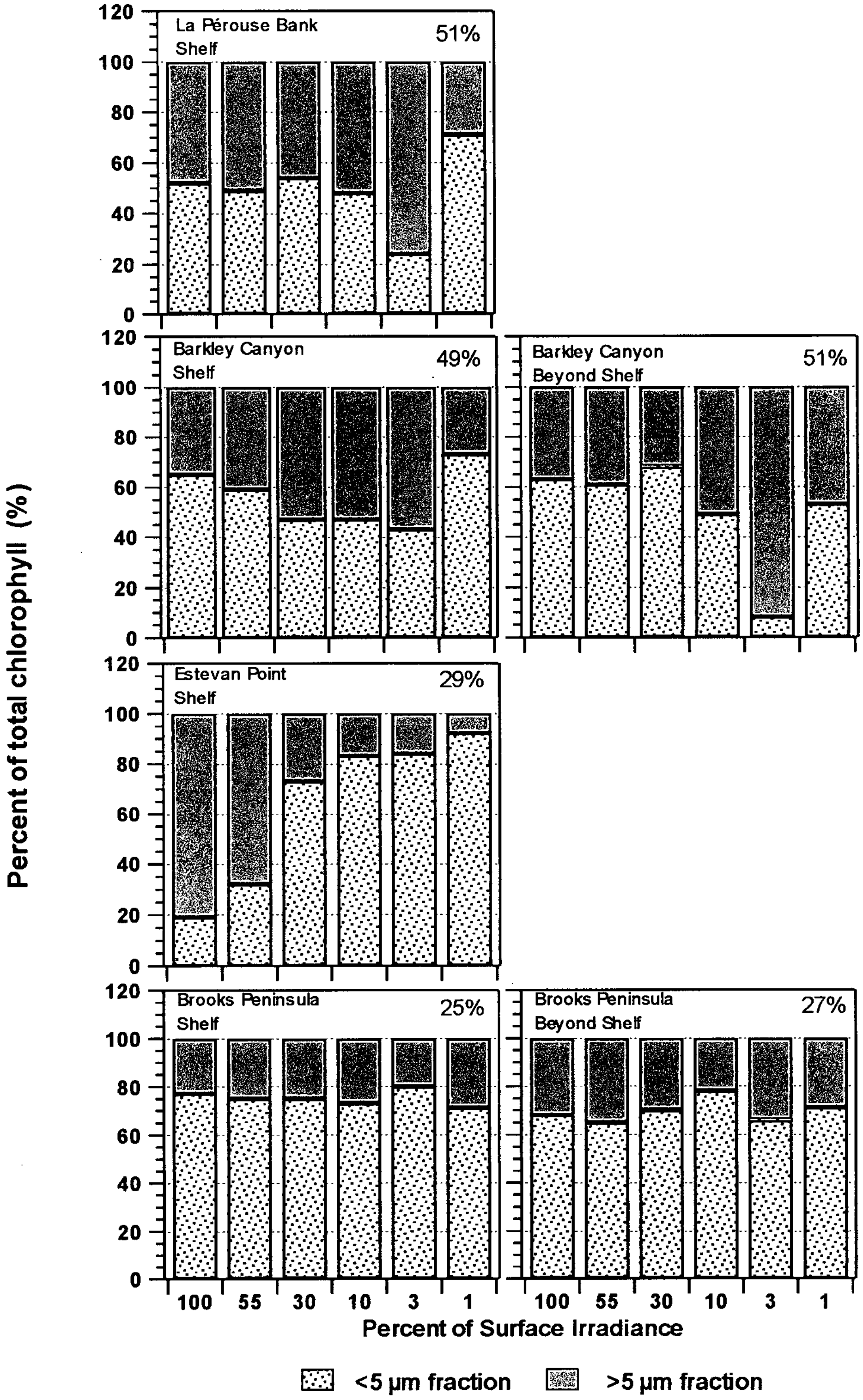

Figure L.2 Relative contribution of <5 µm size fraction and >5 µm size fraction to chlorophyll at each light depth for the shelf and the beyond shelf station of each transect during Oct. 1997. Relative contribution of >5 µm fraction of depth integrated chlorophyll in right hand corner of each graph.

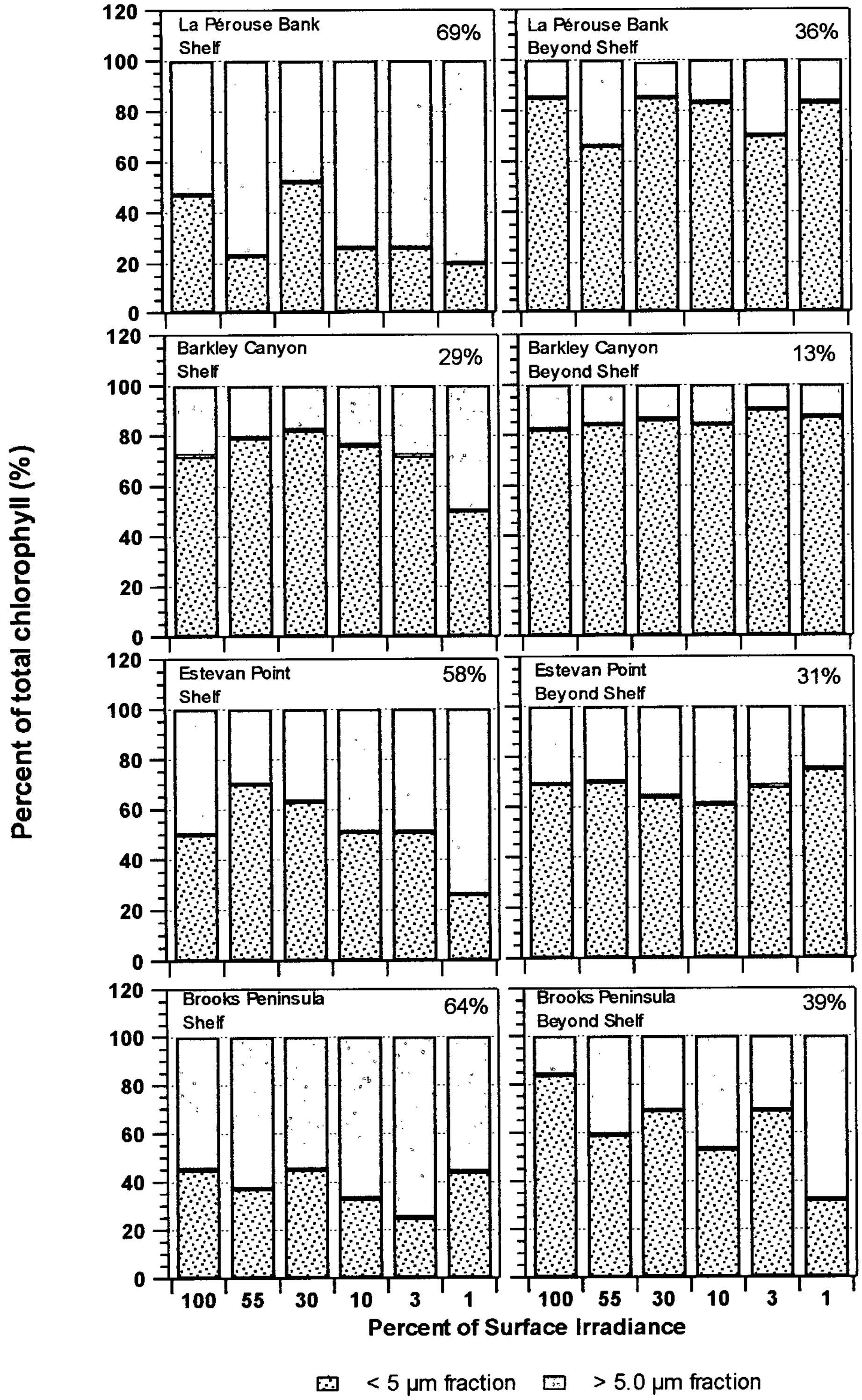

Figure L.3 Relative contribution of <5 µm size fraction and >5 µm size fraction to chlorophyll at each light depth for the shelf and the beyond shelf station of each transect during May 1998. Relative contribution of >5 µm fraction depth integrated chlorophyll in right hand corner of each graph.

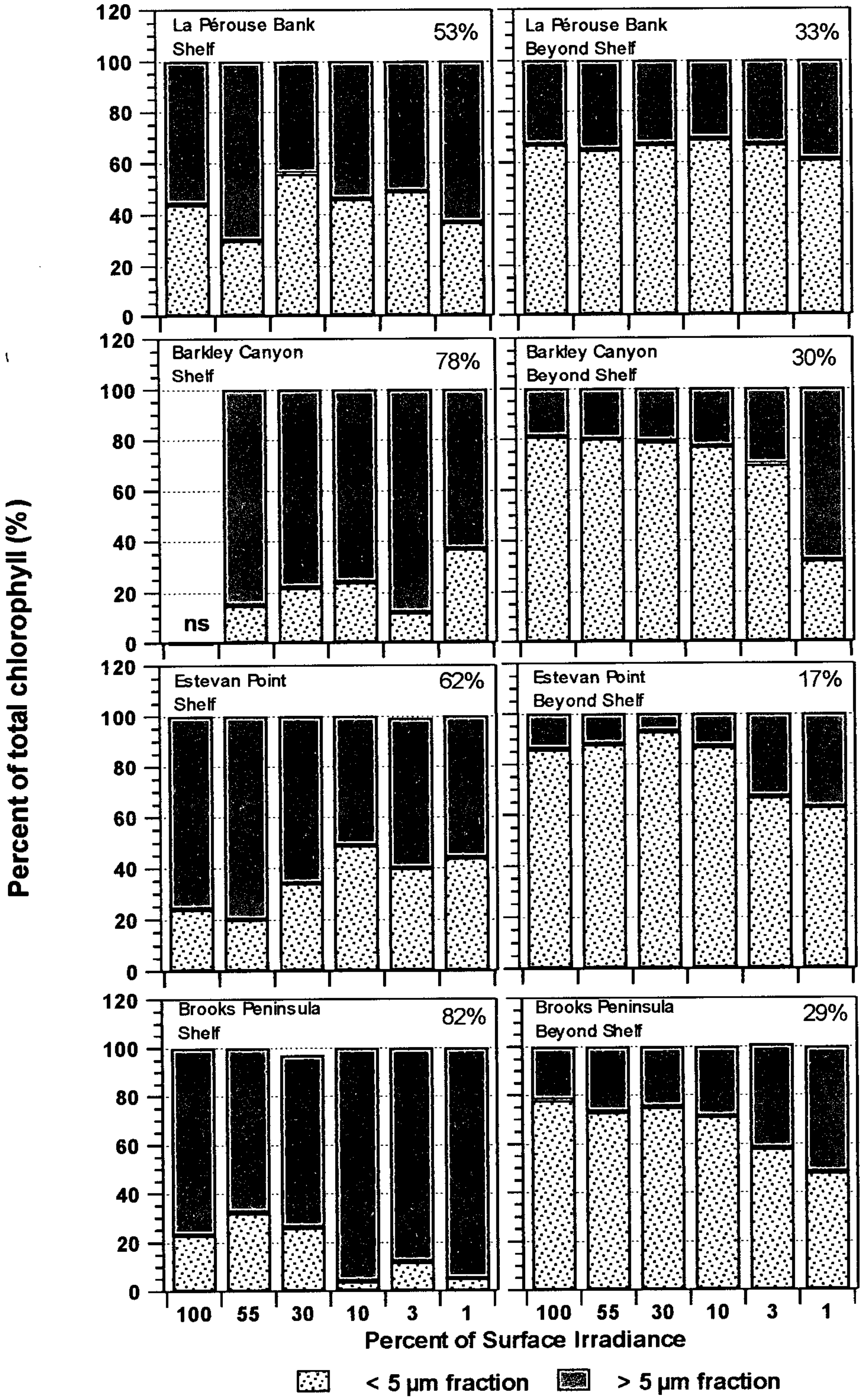

Figure L.4 Relative contribution of <5 µm size fraction and >5 µm size fraction to chlorophyll at each light depth for the shelf and the beyond shelf station of each transect during Oct. 1998. Relative contribution of >5 µm fraction depth integrated chlorophyll in right hand corner of each graph. ns=no sample is available.

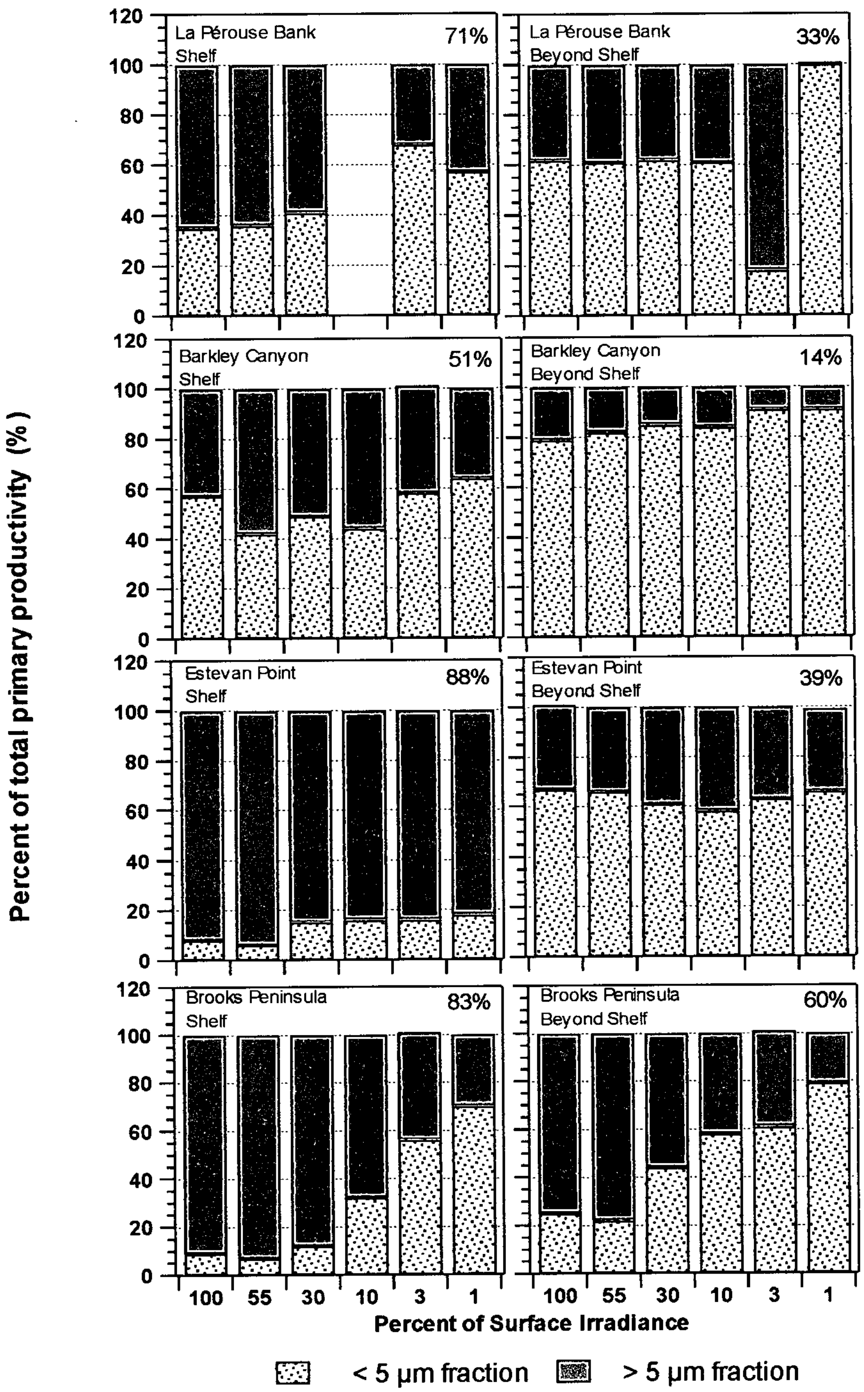

Figure L.5 Relative contribution of <5 µm size fraction and >5 µm size fraction to primary productivity at each light depth for the shelf and the beyond shelf station of each transect during April 1997. Relative contribution of >5 µm fraction to depth integrated primary productivity is in the right hand vorner of each graph.

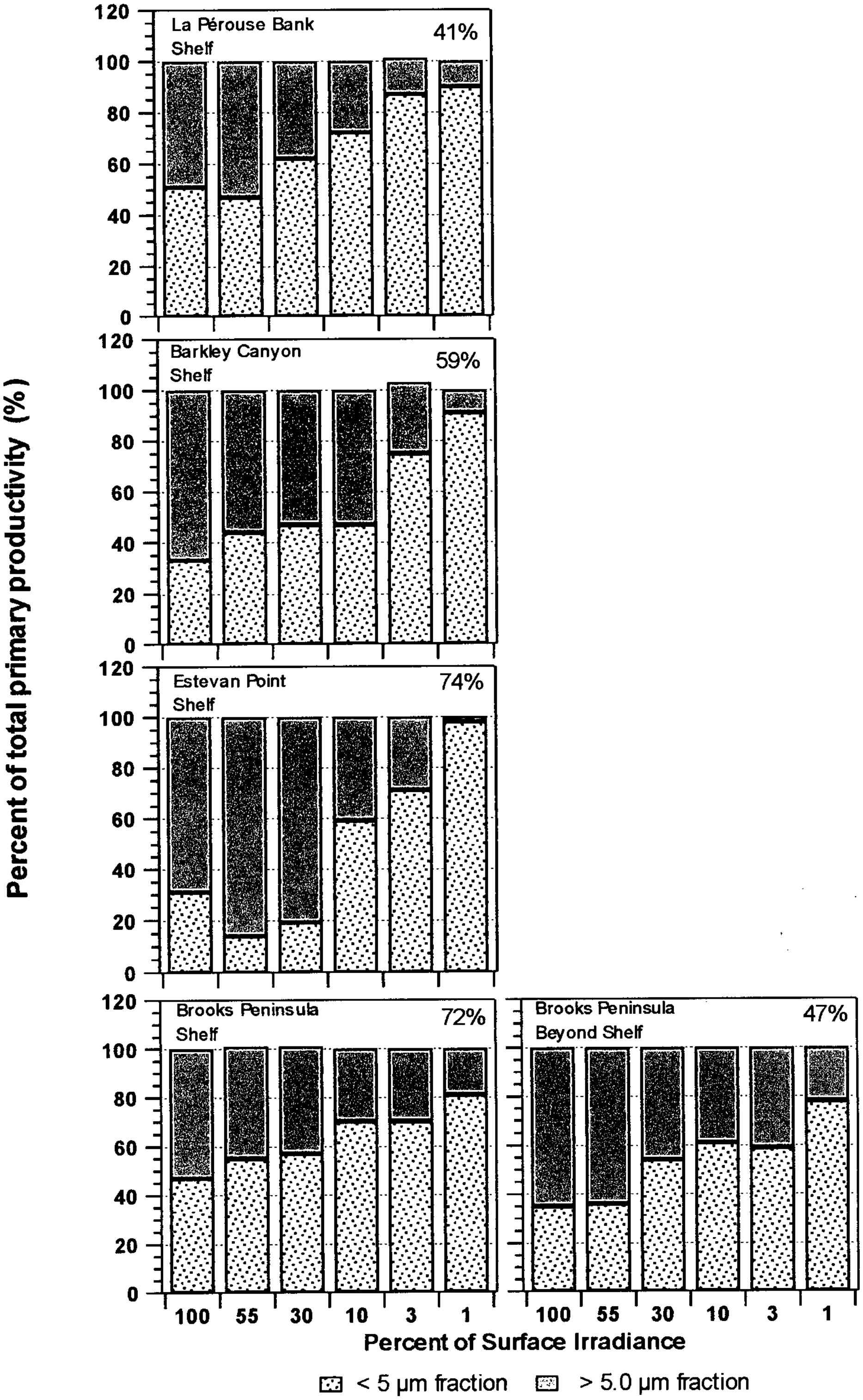

Figure L.6 Relative contribution of < 5.0 µm size fraction and > 5.0 µm size fraction to primary productivity at each light depth for the shelf and the beyond shelf station of each transect during Oct. 1997. Relative contribution of > 5.0 µm fraction to depth integrated primary productivity in right hand corner of each graph.

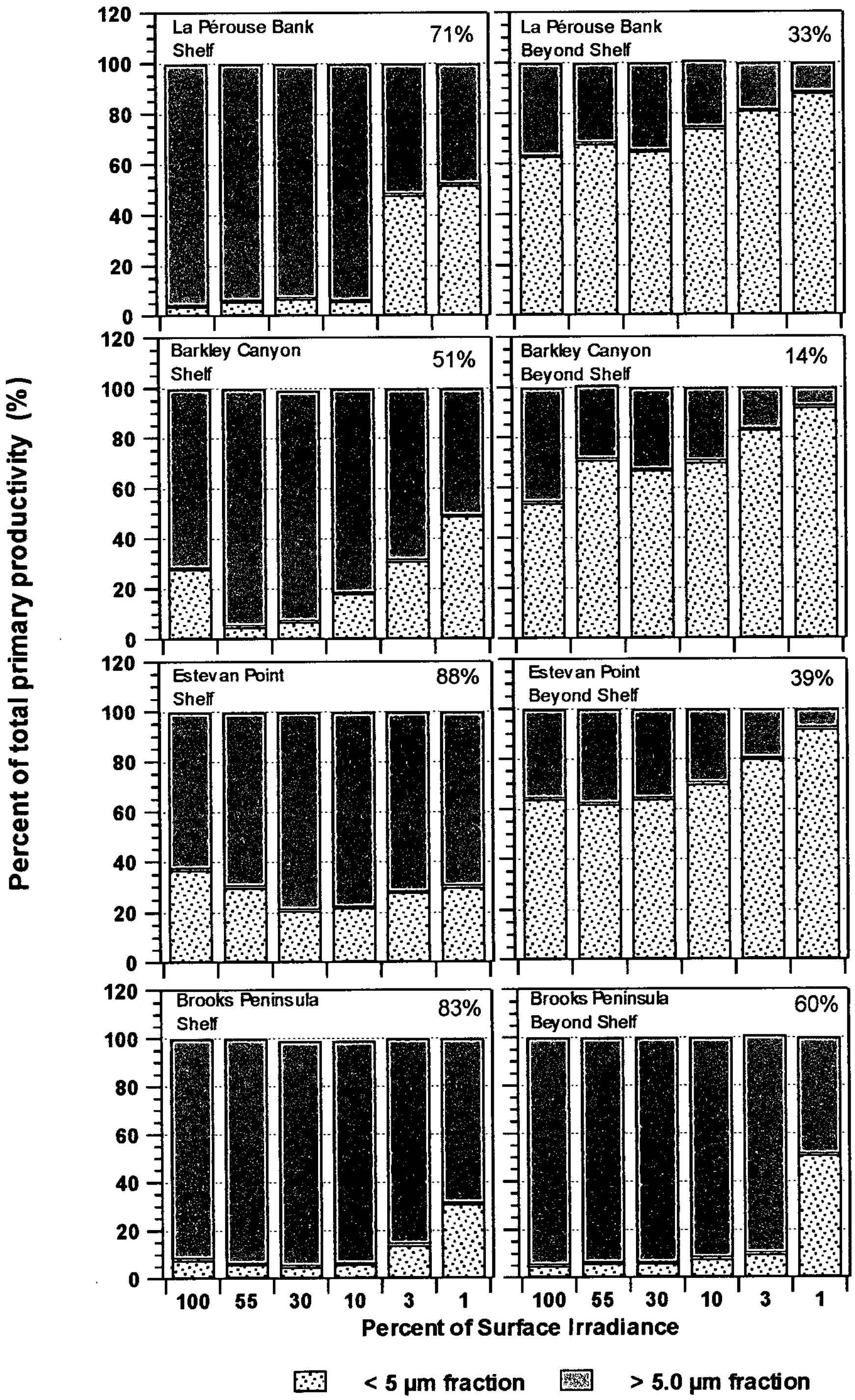

Figure L.7 Relative contribution of < 5 µm size fraction and > 5 µm size fraction to primary productivity at each light depth for the shelf and the beyond shelf station of each transect during May 1998. Relative contribution of depth integrated primary productivity in right hand corner of each graph.

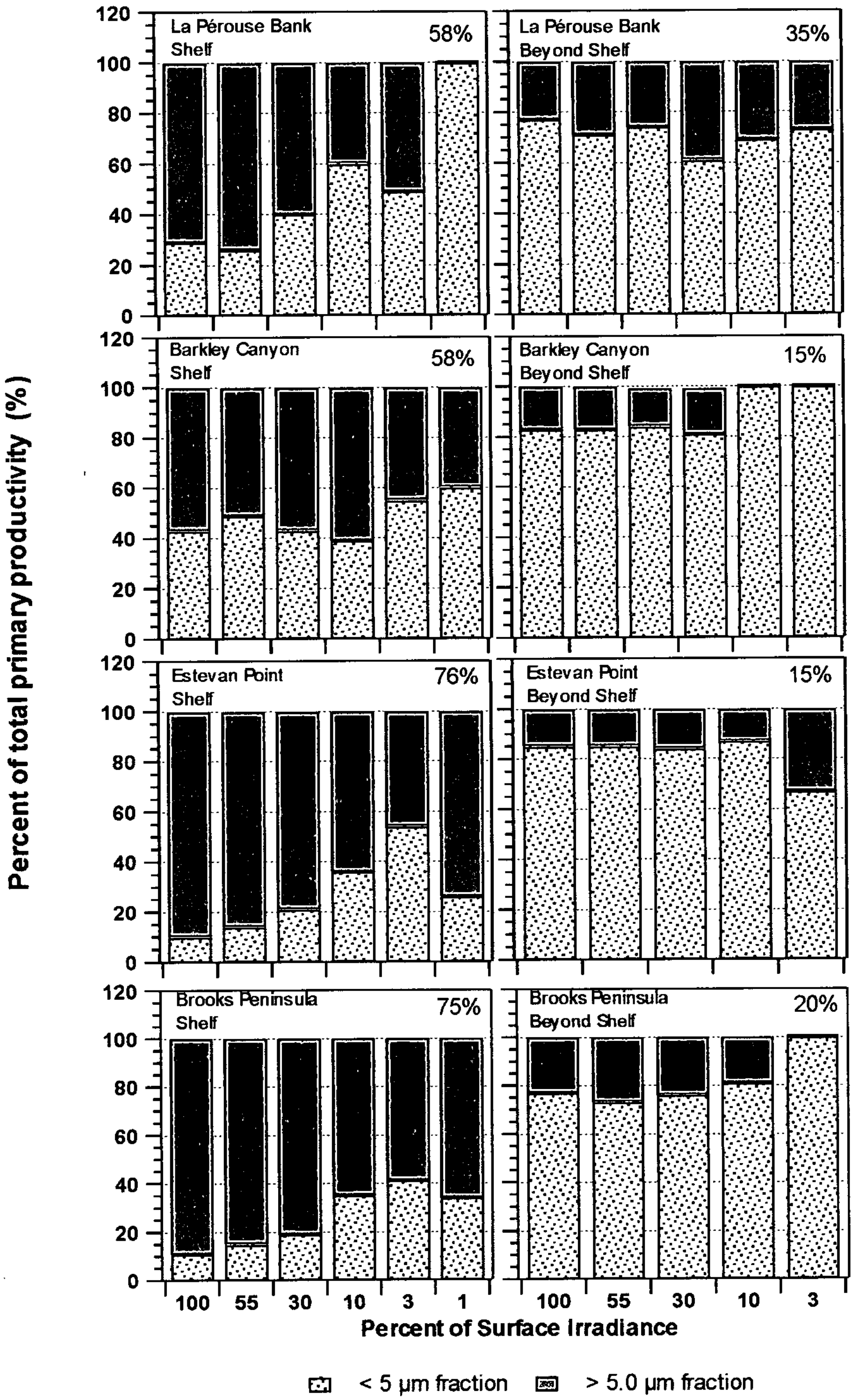

Figure L.8 Relative contribution of < 5 μm size fraction and > 5 μm size fraction to primary productivity at each light depth for the shelf and the beyond shelf station of each transect during Oct. 1998. Relative contribution of > 5 μm fraction to depth integrated primary productivity in right hand corner of each graph.

Table M.1 Total primary productivitiy ±1 S.D. (surface to 1% light depth) for the west coast of Vancouver Island (WCVI) and the shelf and beyond shelf region in 1997 and 1998. Means for 1997, 1998 and for all cruises are given along with the minimum and maximum for all cruises. Numbers in brackets are the number of stations sampled.

	Total Primary Productivity ($g\ C\ m^{-2}\ d^{-1}$)		
Date	**WCVI**	**Shelf**	**Beyond Shelf**
1997			
April	5.2 ± 2.4 (8)	6.9 ±4.9 (4)	3.4 ±2.2 (4)
July	3.5 ±2.8 (6)	5.3 ±2.9 (3)	1.7 ±1.2 (3)
Oct.	3.2 ±3.4 (5)	3.1 ±4.0 (4)	3.3 (1)
1997 cruises	4.3 ±1.1 (19)	5.1 ±3.4 (11)	2.8 ±1.8 (8)
1998			
May	2.8 ±2.5 (8)	3.9 ±2.4 (4)	1.7 ±2.3 (4)
July	6.7 ±8.6 (8)	11.7 ±10.2 (4)	1.8 ±1.3 (4)
Oct.	0.6 ±0.4 (8)	1.1 ±0.4 (4)	0.5 ±0.2 (4)
1998 cruises	3.4 ±3.0 (24)	5.2 ±7.2 (12)	1.3 ±1.7 (12)
All cruises	4.0 ± 0.8 (43)	5.1 ± 2.7 (44)	2.0 ± 0.1 (44)
Minimum	0.6	0.3	0.3
Maximum	6.7	26.1	6.3

Table M.2 Size-fractionated primary productivity (g C m^{-2} d^{-1}±1 S.D.) (surface to 1% light depth) and relative contribution of >5 μm fraction to total productivity off the west coast of Vancouver Island, the shelf and beyond shelf regions in 1997 and 1998. Means for the 1997, 1998 and all cruises are given along with the minimum and the maximum.

	West Coast of Vancouver Island			Shelf Regions			Beyond Shelf Regions		
	PP <5.0 μm	PP >5.0 μm	PP % >5.0 μm	PP <5.0 μm	PP >5.0 μm	PP % >5.0 μm	PP <5.0 μm	PP >5.0 μm	PP % >5.0 μm
April 1997	1.8 ±0.4	3.5 ±3.0	55 ±30	1.5 ±0.3	5.6 ±4.6	73 ±20	2.1 ±1.4	1.4 ±1.2	38 ±20
	n=8	n=8	n=8	n=4	n=4	n=4	n=4	n=4	n=4
July 1997	1.1 ±0.4	2.5 ±2.6	55 ±20	1.1 ±0.2	4.2 ±2.7	73 ±20	1.0 ±0.5	0.7 ±0.7	43 ±10
	n=6	n=6	n=6	n=3	n=3	n=3	n=3	n=3	n=3
Oct. 1997	1.2 ±0.8	1.9 ±2.7	53 ±10	1.1 ±0.9	2.0 ±3.1	54 ±20	1.8*	1.6*	48*
	n=5	n=5	n=5	n=4	n=4	n=4	n=1	n=1	n=1
1997 cruises	1.4±0.4	3.0 ±0.8	54±1	1.2 ±0.8	3.9 ±3.1	69 ±20	1.6 ±1.0	1.1 ±0.9	38 ±15
CV	26%	26%	3%	66%	79%	32%	67%	79%	38%
May 1998	0.7 ±0.6	2.3 ±2.3	62 ±30	0.7 ±0.6	3.2 ±2.1	80 ±11	0.4 ±0.1	1.3 ±2.2	75 ±32
	n=8	n=8	n=8	n=4	n=4	n=4	n=4	n=4	n=4
July 1998	1.6 ±1.1	5.7 ±7.7	61 ±20	1.7 ±1.3	10.0 ±9.0	86 ±5	1.1 ±0.7	0.7 ±0.6	40 ±21
	n=8	n=8	n=8	n=4	n=4	n=4	n=4	n=4	n=4
Oct. 1998	0.3±0.1	0.4±0.4	44±26	0.3±0.1	0.7±0.3	67 ±10	0.4±0.1	0.1±0.1	23±9
	n=8	n=8	n=8	n=4	n=4	n=4	n=4	n=4	n=4
1998 cruises	0.8±0.6	2.7±2.5	56±10	0.9 ±1.7	4.3 ±5.9	78±01	0.6±0.7	0.7 ±1.6	34±30
CV	73%	93%	18%	201%	138%	11%	107%	223%	75%
All cruises	1.1±0.6	2.8±0.2	57±0.02	1.0±0.6	4.1±2.0	72±10	1.1±0.3	0.9±0.5	2.0±10
CV	49%	8%	4%	61%	49%	13%	27%	49%	21%
Minimum	1.2	1.9	44	0.1	0.2	41	0.2	0.1	14
Maximum	1.9	3.6	62	3.2	22.9	93	3.8	4.6	91

* 1 station only